TOWARDS A NEW HOSPITAL ARCHITECTURE: AN EXPLORATION OF THE RELATIONSHIP BETWEEN HOSPITAL SPACE AND TECHNOLOGY

by

Angela Burke, MA Art in Architecture, Dip. Arch. (Hons.), B. Arch. Sc. (Hons.)

A Thesis presented to University of East London for the degree of

DOCTOR OF PHILOSOPHY

Supervisor Dr. Renee Tobe

School of Architecture, Computing and Engineering

University of East London

January 2014

Abstract:

Present urban acute NHS hospitals are rigid architectural structures composed of spatial and medical planning requirements that are underpinned by complex inter-related relationships. One assumed relationship is medical technology's affect upon hospital space. There's limited research exploring the relationship between NHS hospital space and medical technologies. Furthermore, little is known about the implications of emerging technologies (ETs) on future urban acute NHS hospital space. This study investigates the link between hospital space and medical technology to visualise the spatial consequences of incorporating anticipated medical ETs into future urban acute NHS hospitals.

A unique single futures prospective methodology is adopted with a mixed methods approach. This includes historical research, a quantitative investigation of four London case studies and a literature exploration of three medical ETs (biotechnology, robotics and cyborgization). Primary data generated from this study forms the basis for creating scenarios of future urban acute hospital environments. Findings reveal that medical technologies impact directly on hospital space, thus, confirming the existence of a link between hospital space and medical technologies. Results also reveal that even without nanotechnology progression, medical technologies decrease in equipment size during the course of their development. This trend contradicts recent medical planning practice which 'super-sizes' high-spec hospital rooms (see Chapter 3). Additionally, a campus-styled hospital typology is determined as the preferred flexible design solution for creating sustainable 21st century urban acute NHS hospitals. Findings lead to recommendations that guide medical planners with the future-proofing of acute hospital space by providing insight and alternative medical planning solutions that incorporate medical ETs into future urban acute NHS hospitals.

TABLE OF CONTENTS

PAGE NO.

CHAPTER

PART I: THESIS FRAMEWORKS AND STRUCTURE

Chapter 1: Introduction

Chapter 2: Thesis Frameworks

Chapter 3: Methodological approaches

PART II: EXPLORING TECHNOLOGY’S RELATIONSHIP WITH HOSPITAL SPACE

Chapter 4: Historical influences of UK hospital space

Chapter 5: Technology's relationship with hospital space

Chapter 6: Typological Case studies

PART III: EXPLORATION OF MEDICAL ET IMPLICATIONS AND VISIONS FOR FUTURE HOSPITAL SPACE

Chapter 7: Exploring the future - medical ETs and practice

Chapter 8: Formation of future scenarios

Chapter 9: Conclusion

Abbreviations

3D	3-dimensional
A&E	Accident & Emergency
ADB	Activity Data Base
AGV	Automated guided vehicle
AI	Artificial Intelligence
AIDS	Acquired immunodeficiency syndrome
Amigo	Advanced Multimodality Image Guided Operating
BCI	Brain-computer Interface
Bio. Eng.	Biomedical Engineering
C&W	The Chelsea and Westminster hospital
Cath. Lab.	Cardiac Catheter Laboratory
CCU	Critical Care Unit
CD	Compact disc
CE	Chief Executive
CIAM	Congres Internationaux d’Architecture Moderne
Comms.	Communications
COW	Computer-on-wheels
CSSD	Central Sterile Service Department
CT	Computer Tomography
D&B	‘Design and build’
D&T	Diagnostic and Treatment
DGH	District general hospital
DHEF	Department of Health Estates & Facilities Division
DHSS	Department of Health and Social Services
DNA	Deoxyribonucleic acid

DOH	Department of Health
DSU	Day Surgery Unit
DTM	Design Team Members
EAU	Emergency Assessment Unit
EBD	Evidence Based Design
ECG	Electrocardiograph
EDC	Emergency Data Centre
EMR	Electronic medical record
EMS	*Emergency Medical Service*
ENT	Ear, Nose & Throat
ETs	Emerging Technologies
FDA	Food and Drug Administration (US)
FHN	Future Healthcare Network
FM	Facility Management
GBA	Gross Building Area
GCA	Gross Communications Area
GDA	Gross Departmental Area
GDP	Gross domestic product
GFMA	Gross Facility Management Area
GMO	Genetically modified organism
GOSH	Great Ormond Street Hospital for children, London.
GP	General Practitioner
GPA	Gross Plant Area
HBD	Hospital Buildings Division
HBN	Health Building Notes
HCSTC	House of Commons Science and Technology Committee

HDR	Hospital design research
HDU	High-dependency Unit
HEMS	Helicopter Emergency Medical Service
HIV	Human immunodeficiency virus
HTM	Health Technical Material
IC	Integrated circuit
ICU	Intensive Care Unit
IOW	Isle of Wight
ISO/TS	International Standardization Organization/Technical Specifications
IT	Information Technology
IV	Intravenous solution
LD	Llewellyn-Davies (architects)
LET	Light emissions/laser technology
LIC	Laboratory-in-a-cell
LIFT	Local Improvement Finance Trust
LOC	Lab-on-a-chip
m	meters
M&E	Mechanical and electrical
MARU	Medical Architecture Research Unit
MASH	Mobile Advanced Surgical Hospital
MAU	Medical assessment unit
ME	Molecular engineering
MEMS	Micro-electro mechanical systems (Microtechnology)
MHRA	Medicines and Healthcare products Regulatory Agency
MIS	Minimal invasive surgery
MIT	Massachusetts Institute of Technology

MOH	Ministry of Health
MRI	Magnetic Resonance Imaging
MRSA	Methicillin-resistant Staphylococcus aureus
MS	Multiple sclerosis
NASA	National Aeronautics and Space Administration
NEAT	New and emerging applications of technology
NHS	National Health Service
NICU	Neo-natal Intensive Care Unit
NIHR	National Institute of Health Research
NM	Nuclear Medicine
NNI	National Nanotechnology Initiative (US)
NPT	Near-Patient Testing
Offices	All administration areas
OPD	Out-patient Department
OT	Operating Theatre
PAPHE	Present and future of European hospitals heritage
PDA	Personal digital assistant/palmtop
PET	Positive emission tomography
POCT	Point-of-care testing
POE	Post-operative evaluation
PFI	Private Finance Initiative
POS	Patient overnight stay
PTO	Patent & Trademark Office (US)
R&D	Research and development
RC	Robotics-Cyborgization
RFID	Radio frequency identification

RIBA-II	Robot for Interactive Body Assistance’
RIVA	Robotic IV Automation
RLH	Royal London Hospital
RP6	Remote presence 6
SARS	Severe Acute Respiratory Syndrome
SOA	Schedule of Accommodation
sqm	Square Meters
Support	Includes departments such as Laundry and Kitchen
TB	tuberculosis
The Barts	St. Bartholomew’s Hospital, London
TOP	Technological Operational Policy
UAS	Unassigned space
UAT	Urgent-acute-trauma
UCLH	University College London Hospital
UK	United Kingdom
UN	United Nations
US	Ultrasound
USA	United States of America
W&C	Women and Children
Wards	In-patient ward areas
WC	water closet
WWI	World War I
WWII	World War II

Chapter 1: Introduction

"Nobody made a bigger mistake than he who did nothing because he could do only a little"

Edmund Burke

1.0 Introduction

This thesis investigates technology's relationship with hospital space to understand the implications of emerging technologies (ETs) on future urban acute hospital space. Chapter 1 commences with an introductory background to the thesis and the National Health Service's (NHS) recent hospital building activity (2000-2012). This is followed by an outline of thesis concerns which lead to the identification of the thesis argument, aim and objectives. Thereafter is a justification for the thesis and why the relationship between hospital space and technology is explored. The chapter closes with an outline of thesis scope and structure.

1.1 Background to thesis

The British Labour government's *NHS Plan 2000* set out a new NHS hospital rebuilding agenda. This programme neared completion by 2012 resulting in over 100 newly built and renovated acute hospitals (Department of Health, 2007:3). The architectural outcome of this governmental policy has generated a new landscape of 'state-of-the-art' acute hospitals which have been delivered predominantly through a Private Finance Initiative[1] (PFI) process that strongly emphasises economical solutions. However, questions have emerged regarding the durability of PFI NHS hospitals (Gates, 2005:7). Central to concerns is the future flexibility of current NHS hospitals. From a medical planner's perspective, this thesis investigates the necessity for spatial flexibility based on the ineffective spatial evolution of 20th century NHS hospitals. Specifically, this study focuses on the link between hospital space and technology which establishes the need for flexibility within future NHS hospitals. From this background, this empirical study focuses explicitly on urban acute hospitals to examine the spatial challenges facing hospitals with large cutting-edge medical technologies.

---

[1] See Glossary.

By 2012, technologies are necessary for delivering clinical excellence. Operationally, the integration of technology into hospitals drives a healthcare system fundamentally structured upon technology. Proof of technologies' importance is demonstrated when clinical or non-clinical equipment fail (see Appendix A.1). A potential outcome of equipment failure is the possibility of unnecessary patient mortality. Therefore, the importance of technology in the daily running of current NHS hospitals cannot be over emphasised and it is justifiable to state; 21st century hospitals cannot function as effectively without technology. This prominent status is anticipated to continue through ETs[2] which are classified as innovative science-based novel technologies that create new or transform existing industries (Srinivasan, 2008:633-40). Anticipations for medical ETs, such as, nanotechnologies and robotics, visualise future healthcare practices as very different (Freitas, 2005:1-21). Therefore, if technology is an assumed fixture within future acute hospitals, consideration for its spatial requirements is a necessity. Upon Edmund Burke's inspiration, that there is worth in doing *only a little*, this study analyses the medical planning and spatial impact of anticipated medical ETs on future urban acute hospitals.

1.1.1 Thesis concerns

The thesis is underpinned by three main concerns pertaining to the durability of PFI NHS hospitals. Collectively, these issues lead to the identification of the thesis argument.

The first major concern is technology's influence upon hospital space. A key element of this is establishing the existence of an assumed relationship between hospital space and technology. Determining this relationship requires the evolutionary path of technology

---

[2] See Glossary.

development in hospitals to be explored. However, proving this assumed relationship is core to underpinning the main research concern: medical ET's effect on future urban acute hospital space. This central concern is supported by literature that predicts a radically different future for medical practice, such as, the use of nanorobots or audiopaint, and raises two issues:

(i) What are the anticipated changes for future medical technologies and practice?

(ii) How will the incorporation of medical ETs affect future hospital space?

Therefore, to invoke the scale of spatial challenges that lie ahead for urban acute hospitals, future technological changes must be identified to allow for appropriate medical planning solutions.

The second concern involves the latest high-tech NHS hospitals and their 'state-of-the-art' status. In the light of anticipated medical ETs, this study of current NHS hospitals raises questions regarding their future durability. For example,

(i) Are PFI NHS hospitals sufficiently future-proofed to spatially cope with medical ETs?

(ii) Will current 'state-of-the-art' PFI NHS hospitals sustain complete clinical and spatial functionality throughout their contracted 35-40 year life span?

To understand the potential issues facing PFI NHS hospitals, the current status of spatial design in NHS hospitals must be explored and defined. For example, why were the majority of 1980s NHS hospitals rebuilt within 20 years? Once identified, lessons can be learned from trends and outcomes of previously ineffective hospitals to confirm or challenge the doubts concerning the longevity of PFI NHS acute hospitals.

Both of these key concerns are linked through their need to respond to an unknown future which leads to a third, and main, concern regarding how future urban acute hospitals should be designed. This involves examining medical planning processes to understand the anxieties expressed by medical planners regarding PFI NHS acute hospitals. The present adoption of an obsolete hospital design paradigm is central to these anxieties. Reflecting 20th century medical and technological demands, this PFI NHS model is supported by a similarly out-dated NHS Health Building Notes (HBN) guidance. It is the view of this thesis that this is not the design solution for 21st century high-tech acute hospitals especially with ETs rapidly becoming a reality within medical practice. Therefore, if technology is changing rapidly and the durability of PFI NHS hospitals is highly questionable, the spatial planning of ‘state-of-the-art’ hospitals will be greatly tested over the next thirty years.

1.2 Thesis argument

Based on the above medical planning concerns, the thesis argument is clearly set out:

> Based on a defined relationship that exists between hospital space and technology, anticipated medical ETs in future medical practice will radically affect future urban acute hospital space.

In a bid to prove this argument, four thesis objectives were formed. Objectives are supported by numerous sub-questions listed in Appendix A.2.

1.3 Objectives

The aim of this research is to investigate the relationship between hospital space and technology in order to explore the spatial implications of medical ETs on 21st century urban acute hospitals. The objectives of this study are to:

1. Confirm the assumed relationship between hospital space and technology
2. Investigate technology’s influence as a driver of hospital medical planning

3. Investigate the design implications of medical ETs for future urgent-acute-trauma[3] (UAT) treatments and associated hospital spaces
4. Assess the necessity for flexible hospital design solutions.

1.4 Importance of thesis

Contemporary hospital design research (HDR) focuses heavily upon patient well-being and clinical issues. These include; the effect of healing environments on patient outcomes; the implications of single patient-bedroom designs upon medical errors (Rubin et. al., 1998; Ulrich et. al., 2004, 2008:61-125). Studies that focus on medical ETs and NHS hospital space appear non-existent. Hence, in researching the influence of medical ETs on future urban acute hospital space, this study contributes to the gap in this body of knowledge and, for this reason, is an original contribution.

There is a growing expectation for quantitative data to support all new hospital designs due to the financial responsibilities of maintaining the United Kingdom's (UK) multi-billion pound NHS estate. As a result, Evidence Based Design (EBD) is becoming more prominent in the justification of each hospital design (Bardwell, 2007:22). This thesis produces a body of empirical evidence that will inform the medical planning of future hospital space with EBD. All Design Team Members[4] (DTMs), such as, medical and health planners, clinicians and Trust managements as well as Department of Health (DOH) policymakers will find the study useful as a tool to understand and inspire the creation of 21st century hospital environments.

Strategies for future-proofing urban acute hospital space require an understanding of current hospital design drivers and the identification of anticipated trends that are

---

[3] See Glossary.
[4] See Glossary.

driving spatial change. Two underlying forces exist in the medical planning of urban acute NHS hospitals. These are complexity and on-going change which this thesis explores explicitly by examining medical technologies and ETs. The thesis advances the understanding of how technological change will affect hospital space but the creation of a new hospital design model is unachievable within this thesis. Numerous non-spatial design drivers, such as economic and managerial influences, need to inform a new medical planning model which requires specialist knowledge outside my scope as a medical planner. Nevertheless, by critically assessing technology's influence upon the configuration of hospital space, the thesis provides alternative medical planning solutions at different design scales[5] to inform a new hospital design model.

1.5 Scope of thesis

This critique of current hospital medical planning explores the relationship between hospital space and technology to determine if present urban acute PFI NHS hospitals can appropriately respond to medical ETs.

Part I is a three-chapter discourse outlining theoretical and contextual frameworks as well as the methodological processes contributing to the overall thesis structure. In particular, key hospital design influences and concerns are investigated with outcomes for further research identified and detailed in Chapter 3.

Part II consists of a three-chapter debate that defines the relationship between hospital space and technology. Chapter 4 begins this exploration by investigating the historical development of hospitals whereas a parallel discussion in Chapter 5 examines the growth of medical technologies and its historical participation in hospitals. In an attempt

---

[5] See section 2.2.1 for design scale definitions.

to measure this relationship, four central London Accident and Emergency (A&E) NHS hospitals are analysed quantitatively in Chapter 6. A case study approach examines the impact of technology on past and present hospital typologies.

Part III is a three-chapter discussion exploring the future of acute hospital space. Chapter 7 details anticipated medical ETs and their implications for future medicine and hospital space. Thereafter, key trends for future medical practice are linked to the hospital environment through the formation of UAT clinical scenarios in Chapter 8. This is followed by a conclusion chapter which provides recommendations and guidance for medical planners in the design of future urban acute hospitals with respect to medical ETs.

Chapter 2: Thesis frameworks

"It is not the strongest species that survive, nor the most intelligent, but the ones most adaptable to change"

Charles Darwin

2.0 Introduction

Chapter 2 provides a framework from which to explore the main thesis argument. This chapter's theoretical and contextual discussions upon hospital space and technology formed this study's framework. Divided into two distinct sections, the first section reviews 20th century hospital medical planning with respect to flexible design solutions. Investigations examine successful 20th century hospital designs to identify essential medical planning principles. This theoretical discussion critiques the importance of flexibility and its relevance to current PFI NHS hospitals. As Darwin observed, survival is driven by *the ones most adaptable to change*. This is followed by an outline of current medical planning and PFI processes responsible for creating the latest legacy of NHS hospitals. Additionally, this section seeks to examine the flaws surrounding current medical planning practice which lack consideration for evolving medical technologies. The second section focuses on technology which begins with a review of the fundamentals of ETs. The works of both electronic engineer Gordon Moore (ex-CE, Intel) and physicist and Nobel Laureate, Richard Feynman inform the theoretical framework by defining the scientific principles that underpin future technological change. Thereafter, ET anticipations for future medical practice are outlined and followed by a review of the contextual aspects of medical technologies in current NHS acute hospitals. The capabilities of medical ETs are introduced by the scientific works of physicists Michio Kaku and Robert Freitas Jr. as well as computer scientist and inventor, Ray Kurzweil (Google's Director of Engineering, 2013). The chapter concludes by reinforcing the concerns associated with inflexible designs supporting the necessity for an empirical investigation into medical ET's influence upon future urban acute hospital space.

2.1 Theoretical Framework: Hospital Medical Planning

Architectural products from the recent PFI process have provoked the latest discourse for flexible hospital design. Amongst other concerns, one predominant anxiety for PFI hospital buildings is that these ‘state-of-the-art’ environments are predicted to ‘be defunct within five years’ (Gates, 2005:7). To invoke the accuracy of this opinion, this section theoretically examines flexible hospital design to establish its necessity as an integrated design component to create successful hospital building life-spans. Driving this fundamental exploration is a concern for future technological change which anticipates medical transformations to revolutionise future medical practice. How hospitals will adapt to change depends on their available flexible options, opening debatable possibilities for the premature invalidity of PFI NHS acute hospitals.

Architectural flexibility is defined consistently, such as, Griffin & Roughan’s interpretation:

> Flexibility really means the ability to locate into the building, over its lifetime, a variety of functions, many of which might not be anticipated at the design stage. Indeed, the variety of functions will suggest some form of ‘universal’ building type which might be adaptable to new function within its shell in order to justify its capital cost and avoid wasteful and premature demolition (Griffin & Roughan, 2006:15).

List of terminologies: Flexibility
3.4 A ‘flexible’ design enables different activities to be accommodated in a given space without physical re-arrangement taking place. 3.5 An ‘adaptable’ design allows physical re-arrangement of building elements, services and furniture (Department of Health Estates & Facilities Division (DHEFD), 2005:8).
‘Flexible (design) solutions’ refer to the combined terminologies of flexible and adaptable design listed in points 3.4-5 above.

Table 2. 1 List of thesis terminologies: Flexibility.

While a recurring theme for defining flexibility is ‘an easy response to change’ or ‘adaptability’, terminologies are often inconsistent and interchange throughout architectural literature. For clarity, this thesis adopts three terminologies, listed in Table 2.1, which are drawn from the NHS’s HBN15 guidance.

Transferring these definitions into a set of principles for flexible hospital design is vital to determining the durability of PFI NHS hospitals. Hence, this section’s review is focused on defining these medical planning tenets. As it will be shown, flexible design solutions in hospital architecture are not a novel theoretical phenomenon. Throughout the discourse of 20th century hospital architecture, numerous innovative architects emphatically expressed the obligatory importance of flexibility in hospitals. To superimpose the relevancy of their theoretical significances onto PFI NHS hospital typologies, the thesis is informed by works from two Modernist architects, Alvar Aalto and Le Corbusier, and one healthcare architect, John Weeks. Their hospital typologies were chosen for three explicit reasons. First, they exemplify a variety of 20th century hospital design templates. Second, they were designed specifically with flexible design solutions in mind. Third, and most importantly, all of these hospital typologies offer successful medical planning solutions compared with other 20th century hospital designs discussed in Chapter 4. Each typology is examined individually to understand why all three architects agreed upon one underlining strategic principle: flexible solutions are paramount to successful hospital buildings.

Numerous typologies exemplify 20th century hospital design but to address the concerns set out in Chapter 1, only templates relevant to the sustainability of PFI NHS hospitals justified exploration. Hospital typologies were divided chronologically into three categories all of which contained three pertinent characteristics: to reflect alternative medical planning approaches; conceptual innovation; flexible hospital design solutions. Long periods of British hospital building inactivity occurred throughout the 1900s. Hence, it was necessary to consider European hospital typologies.

(i) 'Sanatorium' model (1900-50s): Sanatorium typologies of note include Bijvoet and Duiker's Zonnestraal, Netherlands (a precedent of Paimio) and Aalto's Paimio, Finland (see Figure 2.1). These European precedents were later emulated in Britain, such as, the Sully Hospital, Cardiff (1931-7). This hospital's medical planning received no recommendations and was therefore unavailable for critical examination (Hughes, 2000:29). In contrast, Aalto's Paimio sanatorium is acclaimed widely as innovative and greatly influencing other designs, for example, Australian hospitals the Mercy Hospital, Melbourne (1938) and King George V for Women, Sydney (1942) (Willis, 2002:46-7).

(ii) 'Vertical' model (1950-1980s): Burgerspital Hospital, Switzerland (1945) and Soder Hospital, Sweden (1938-43) revolutionised mid-20th century hospital design based on new modern and vertical architectural forms (see Figure 2.2). However, by the time the NHS organised its hospital construction programme, this design model had progressed architecturally. One architect, able to realise his then current theories, was British healthcare architect John Weeks. His Northwick Park Hospital, UK (1962-70) embraced modern architecture and the recently formed NHS organisation into a new hospital typology. Resulting from Britain's first and last national hospital building programme, the relevance of this typology is considered significant within the context of recent PFI NHS design.

(iii) 'Horizontal' model (1980s-2000): Two unrealised examples proved conceptually innovative - Paul Nelson's St. Lo Hospital, France (1949) and Le Corbusier's Ospedale

Civile, Italy (1965). While St. Lo's was conceptually important as a precedent to Gordon Friesen's Automated Hospital in America, this new 'matchbox-on-a-muffin' typology typified another vertical hospital building (see Figure 2.3). Alternatively, the Ospedale Civile offers a variance from the then popular vertical hospital typologies, which was based on Weeks' principles for Northwick Park Hospital. Ospedale Civile's horizontal medical planning strategy preceded the predominantly unsuccessful 'Nucleus' typology that dominated NHS hospital design between 1970-2000.

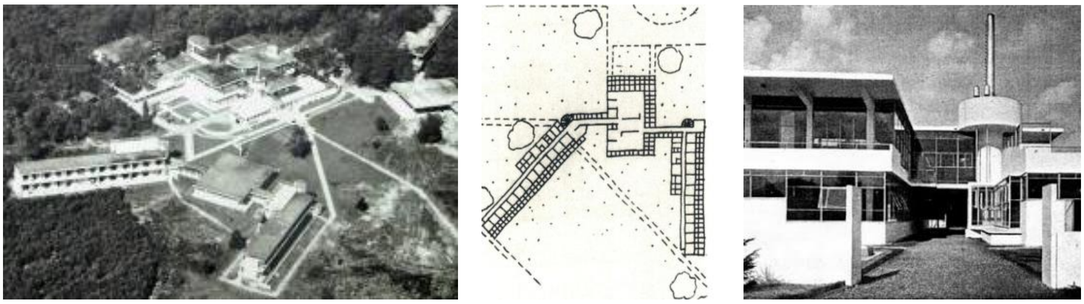


Figure 2.1 Bijvoet&Duiker's Zonestraal Sanatorium, 1926-8 (Pearson, 1978:87-8)

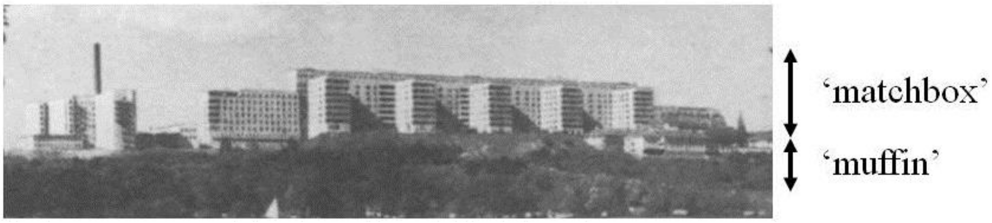


Figure 2.2 Soder Hospital, Stockholm, Hjalmar Cederstrom, 1938-43 (Hughes, 2000a:38).

Figure 2.3 St. Lo Hospital, Normandy, Paul Nelson, c.1949 (Hughes, 2000b:38).

From a medical planning perspective, the next sections' discussions will show that certain 20th century medical planning concepts remain universal in sustaining urban acute NHS hospitals for 2020 or 2050.

2.1.1 The Paimio Sanatorium, Finland (1928-1933), Alvar Aalto.

Finland’s developing healthcare infrastructure resulted in the construction of numerous hospitals in the 1920s. Similar to the UK’s recent hospital rebuilding process, the new sanatorium for Paimio was commissioned through a competitive process. Aalto’s winning design ‘catapulted him into the international architectural elite’ as Paimio became iconic and renowned as universally significant (Schildt, 1994:67; Reed, 1998:28). The success of this innovative sanatorium model can be accounted for through Paimio’s medical planning strategies, which Aalto expressed throughout the hospital’s building.

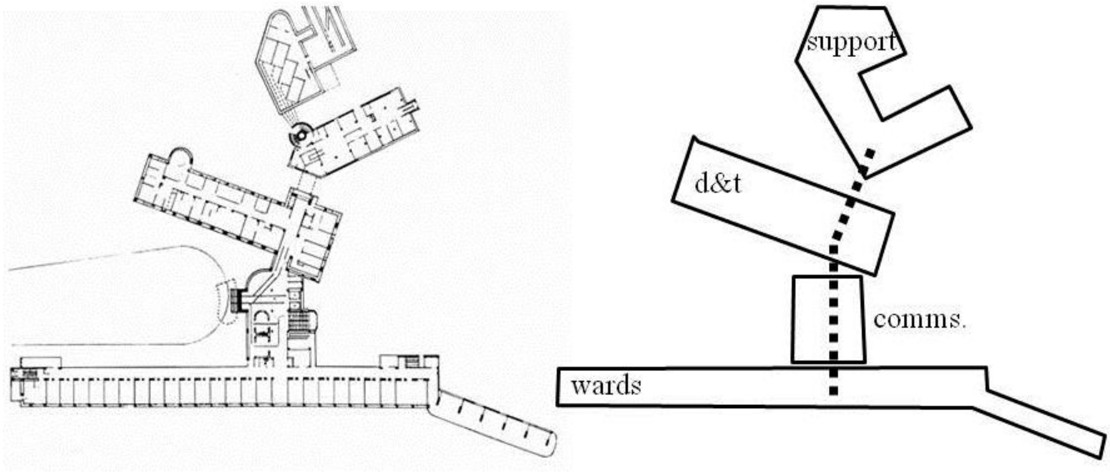


Figure 2.4 Left: Ground Floor Plan, Paimio Sanatorium, 1929-33 (Gossel&Leuthauser, 1991:186). **Right:** Author’s 1:500 medical planning sketch.

Previously alluded, Paimio was ‘a variant of Duiker’s Zonnestraal Tuberculosis Sanatorium’ which was drawn experientially from Aalto’s visit to Hilversum, Holland in 1928[1] (Reed, 1998:28). This event, cited by architect Malcolm Quantrill, allowed Aalto ‘to see a perfect model of functionalist planning on an open site’ (Quantrill, 1983:52). Zonnestraal’s impression upon Aalto is evident throughout Paimio’s design which ‘incorporated many new ideas in hospital design and epidemiology when it was constructed’ in the 1930s (Pearson, 1978:84,92). As architect Paul Pearson argues:

---

[1] After attending the International Congress on Reinforced Construction conference in Rotterdam (May 21st and 24th, Paris), Aalto visited Duiker on his way home with whom he met at the conference.

> In medical terms both Paimio and Zonnestraal were founded on the theory of tuberculosis treatment popular in the late twenties – isolating the patient from the urban environment of smoke and pollution and effecting a cure by allowing him to sit in the sun absorbing solar rays and breathing in fresh air (Pearson, 1978:84-5).

Innovative in structure (concrete frame), interiors (colours and furnishings) and medical planning, the Paimio Sanatorium opened in 1933 to provide a calm environment for the treatment of tuberculosis patients. The functional success of Paimio's typology is palpable from its sustained durability over time. This is represented by the building's functional evolution from a sanatorium to a general regional hospital to its current status as a University hospital[2] (McEvoy, 2005:65). From a medical planning perspective, the success of Paimio's ability to flexibly adapt its functional use is extremely unusual and remarkable. Similarly, Paimio's internal medical planning has changed minimally since its initial opening. For example, Paimio's medical planning strategy for public spaces and circulation remain unchanged with 1:200 alterations including: (i) wards to comply with standards; (ii) the library to a café; (iii) the common room to a lecture hall (McEvoy, 2005:67). These few alterations raise a critical question; why has minimal change occurred during Paimio's eighty-year-old existence? Two salient features explain the success of Paimio's functional evolution: Aalto's version of strategic separation and decentralised standardisation as flexible hospital design solutions.

(i) Strategic separation: Paimio's strategic medical planning concept (1:500) is defined as a linear ward block with a separate treatment and administration facility block. Both are accessed by a connecting separate communications block which refers to access points as well as horizontal and vertical circulation (Noviant, 1933:90). In addition, two buildings to the rear contain support service departments (Gossel & Leuthauser, 1991:186). Observationally, the thesis identifies Paimio's strategic medical

---

[2] Acquired by Turku University (1987).

planning concept to be one of functional and architectural separation (see Figure 2.4). Architectural historian Winfred Nerdinger argues this strategy of Paimio:

> The separation and differentiation of the various functions into distinct and characteristic building parts that preserve their own identity yet are subordinated to the overall scheme of things (Nerdinger, 1999:12-3).

This medical planning model was Aalto's response as to how a building should continue; to adapt to the requirements of the user. This principle of separation strongly dictates Paimio's theoretical medical planning concept, which Aalto advocated throughout his career as a strategic flexible design solution. In particular, Aalto incorporated the same medical planning strategy in his 1930 Zagreb hospital design (see Appendix B.1):

> Aalto provided a main hospital block around five interior courts. But the smaller clinics for Surgery, Internal Medicine, etc., were given separate pavilions (Quantrill, 1983:59).

Reflecting on Paimio's present functional status, its original typology remains intact as a typological form of functional, clinical and architectural separation. This medical planning principle is therefore identified by the thesis as an intrinsic factor towards Paimio's durability. With respect to PFI NHS hospitals, this medical planning strategy remains relevant and employable as a design model. Yet, one could argue this model is irrelevant to urban acute hospitals with site restrictions. However, medical planners should address future flexibility at the initial stages of all new hospital projects. Should the project consist of a restrictive site with no future expansion allowances, rather than manipulate a known unsustainable typology, a logical solution to suggest is an appropriate alternative site that caters for a proven sustainable hospital design model.

(ii) Decentralised standardisation: Aalto's architectural design approach reflects Louis Sullivan's observation of 'form ever follows function' (Sullivan, 1896:4). This basic principle of functionalism, where a building's form is derived from its intended function, informed Aalto's starting point for detailing Paimio (Lampugnani, 1989:112). To achieve a flexible design, Aalto advocated:

> Standardization, one of the chief by-products of the machine age, must be used to obtain the maximum amount of 'flexibility' and variety, rather than be resigned to the dull and monotonous use of reduplicated forms (Pearson, 1978:150).

Aalto believed that 'the conflict between standardization and the need for individuality and variety' should be addressed through a 'decentralized' type of standardisation where 'the role of standardization is thus not to aim at a type, but on the contrary to create viable variety and richness' (Reed, 1998:28,35). Integrated with this approach was Aalto's concern for human functionality which he expressed was not emphasised enough in existing hospital designs (Aalto, 1940). To elaborate, in *The Humanising of Architecture*, Aalto argues that 'to make architecture more human means better architecture' where 'real functional architecture' must function from a human perspective (Aalto, 1940:14-6). Consequently, Aalto advocated that hospital architecture must respond functionally to human orientation, such as: (i) 'a room in a hospital is occupied by people in a horizontal position'; (ii) patients in hospital are 'in the weakest possible condition' (Aalto, 1940:14-6). These pertinent patient-focused design drivers inspired Aalto to develop many decentralised standard details for Paimio. All were delivered through medical planning responses at 1:200 and 1:50 medical planning design scales (see section 2.2.1). Two examples highlight the range of Aalto's intent to create a flexible and adaptable hospital building that responds to the needs of fragile sick patients.

The first example relates to Aalto's belief in the importance of patients' experience. For example, in an inauguration brochure, Aalto focused on 'his efforts to adapt the institution to the patients' subtlest physical and mental needs' rather than architectural details (Schildt, 1986:193). Aalto's strongest response to patients' needs is Paimio's most prominent architectural feature. This is the overhanging ward balconies that allow all in-patient bedrooms access to personal exterior spaces. This direct response to human requirements for fresh air and natural daylight was, and remains, embedded in the hospital's 1:200 medical planning and architectural form. This particular design feature is vital to human well-being and psychology and will always remain significant. After years of deep-spaced windowless hospitals, 'cutting-edge' EBD purports the necessity of natural daylight and views from both patient and non-patient hospital spaces. Many later PFI NHS schemes have benefited from recently published EBD on this subject which reflect Paimio's medical planning theories. For example, patient-focused design is supported by Prof. Roger Ulrich who pronounces its patient recovery and financial benefits adamantly (Ulrich, 1984:420-1). Hence, eighty years on, Paimio's embedded use of decentralised standardisation supports Ulrich's quantitative evidence. Today, Paimio's hanging ward balconies function as Aalto had intended originally. His architectural embodiment of patient needs has endured against functional and technological changes. With respect to PFI NHS hospitals, this design driver remains crucially relevant to the creation of sustainable patient-orientated hospitals that have become dominated by technologies since the 1970s.

The second example of Aalto's decentralised standardisation was delivered through detailed technical solutions:

> The ideas of facilitating industrial construction through standardization and of humanizing standardization...to achieve flexibility and variety (Enajarvi, 1929:37).

Sourced from functionalist ideologies, Paimio is regarded as having 'the best and most established Functionalist traditions in Aalto's own work' (Pearson, 1978:185). So much so that art historian Goran Schildt's description of Paimio is 'every architectural detail had a clinical function and formed part of the treatment' (Schildt, 1994:67). Aalto's commitment to delivering standardisation resulted in almost 100 design elements.

Architectural writer Peter Reed lists these ‘as heating and ventilation systems, daylight arrangements, light fixtures, color schemes, inventions to eliminate noise disturbances, special door handles, etc.’ (Nerdinger, 1999:12; Reed, 1998:29). Two examples of Paimio’s ‘flexible standardisation’ were a noise-reducing patient wash-hand basin and Aalto’s iconic Paimio Chair (see Appendix B.2). This chair, purposely designed to assist tuberculosis patients with breathing, exemplifies Aalto’s attempt for Paimio ‘to function as a medical instrument’ (Schildt, 1994:68-9). In doing so, Aalto’s personalised attention to detail was incorporated as a driving necessity rather than an unsustainable quick-fit solution. This attention to human detail has stood the test of time but was overlooked in many earlier PFI NHS hospitals and may result in their invalidity. Efforts to create flexible and adaptable hospitals only emerged in later PFI schemes through the rationalisation of equipment and universal room types. This strategy of standardisation will offer future functional, clinical and spatial options similar to the flexible design solutions embedded in Aalto’s Paimio Sanatorium.

To summarise, flexible design solutions have been identified for both strategic and internal medical planning. Lessons can be learned from this lauded hospital design to resolve future medical planning problems. Nevertheless, Paimio’s strategic medical planning concepts responded to a green-field and expandable site which may not be as transferable to the context of a typical urban site. The next typology example, whose medical planning strategy was drawn from Paimio, explores a British urban hospital site and its associated medical planning challenges.

2.1.2 Northwick Park Hospital, UK (1962-70), John Weeks.

By the 1960s, the Hospital, Clinical Research Centre and Medical Research Council of the North West Metropolitan Regional Hospital Board were crumbling NHS estates. As part of Enoch Powell's *1962 Hospital Plan* programme, these two facilities were brought together to form the Northwick Park Hospital on one 61 acre site near Harrow (Weeks, 1966:338). The re-design created a modern template for late-20th century British hospital design. This typology epitomises the embodiment of Weeks' medical planning strategies and is examined as an innovative vertical type urban acute hospital.

(i) Background to Northwick Park Hospital

As a practising healthcare architect from the 1950-90s, John Weeks was aware of the medical planning complexities associated with designing largescale hospitals. Flexibility was a central driver of Weeks' approach to hospital design. Three core influences, embedded in Northwick Park, are of extreme relevance to current medical planning.

The first influence was Weeks' philosophy for flexibility which, as historian Jonathan Hughes purports, was derived from physicist Werner Heisenberg's 'uncertainty principle' (1927):

> The impossibility of determining simultaneously both the position and the velocity of atomic particles...opened up the possibility of systematic ambiguity, of a world based on probability rather than uncertainty (Hughes, 2000:96-7).

Weeks' rejection of classical certainties in favour of Hiesenberg's 'probability' principle, embraced a philosophy of flexibility that could respond to spatial unknowns at Northwick Park. This theoretical approach to medical planning is as highly significant to today's onging evolving nature of urban acute hospital space.

The second driving factor was derived architecturally from two Victorian precedent typologies whose standardisation and prefabrication of architectural materials allowed for functional adaptability (see Figure 2.5). Weeks identified these as Isambard Brunel's

Renkioi Hospital, Turkey (Crimean War, 1855) and Joseph Paxton's Crystal Palace, UK (1851) (Weeks, 1963-4:88-9; Hughes, 2000:97). In the case of Renkioi's 2,200 bed military hospital, Brunel describes:

> The whole hospital will consist of a number of separate buildings...all of the same size and shape so that with an indefinite length of open corridor to connect the various parts they may be arranged in any form (Brunel, 1870).

Conceptually, Weeks divided Brunel's design into two categories of 'determinate' pavilions and 'indeterminate' corridors. This classification of Renkioi became central to Northwick Park's medical planning solution (Taylor, 1991:17). Equally, the concept for Crystal Palace, where unobstructed floor space was capable of sub-diving into separate exhibition spaces, influenced Weeks' theories for managing indecisive briefing and spaces for undefined functionalities (Weeks, 1963-4:88). In brief, the juxtaposition of 20th century uncertainty theories against 19th century engineering principles underpinned Weeks' own future-proof medical planning strategy with philosophies from the works of Brunel, Paxton and Heisenberg.

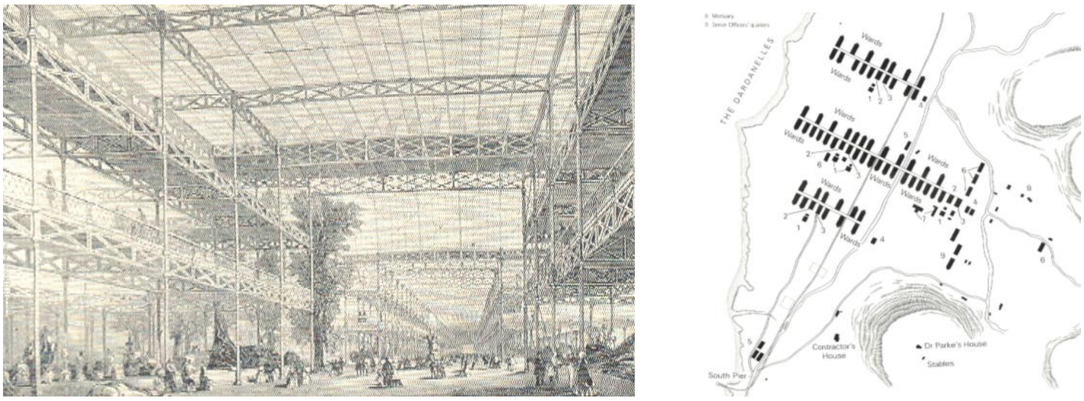


Figure 2.5 Left: Paxton's Crystal Palace (Copplestone, 1991:144). **Right:** Plan of Renkioi Hospital (Richardson, 1998:91, Figure 89).

The third influence was Weeks' flexible design principles which were developed from the identified influences above. Introduced in his *Indeterminate Architecture* at a Bartlett lecture in 1964, Weeks encouraged the use of his hospital design strategies for typically unknown functional futures (see Table 2.2) (Francis et. al., 1999:44). Unlike other architects who engage in theory, Weeks was fortunate to test his future-proof medical planning strategies in the realisation of a large scale ‘indeterminate’ urban acute hospital. Commenting on his design’s durability, the thesis recognises the importance of Weeks’ argument:

> Northwick Park has been designed from the outset to be ‘indeterminate’, that is not only internally flexible but never to reach a ‘final’ size or form. There is no concept of finality built into the design of an indeterminate hospital; at the beginning only the directions and method of growth are decided and not the precise form, which appears as a result of the erosion of time on the original programme. An indeterminate design allows for continuous change and growth of the whole complex without its ceasing function, within limits set by the capacity and shape of the communications’ and service network, and the total size of the hospital site itself (Weeks, 1966:338).

The ideas embodied in this typology revolutionised 20th century British medical planning but this revolution was in theory rather than realisation for reasons described in Chapter 4. Nevertheless, its significance is addressed here to identify the relevance of 1960s flexible medical planning solutions with respect to current PFI NHS urban acute hospitals. For example, the importance of Weeks’ four tenets cannot be underestimated as a set of medical planning principles that stride to advance the sustainability of urban acute NHS hospitals.

***Indeterminate Architecture:* Weeks’ four principles**
1. The major service and communications’ networks are separated physically from the buildings served by them. 2. There is the possibility of independent expansion or replacement of parts of the building complex without affecting the workability of the whole. 3. The design allows for interchangeability or alteration of use of several parts of the building either during the briefing and design period or subsequently during the life of the building. 4. Future building expansion is defined in direction but not in precise form. The communication routes are defined in direction *and* form.

Table 2.2 *Indeterminate Architecture:* Weeks’ four principles (Weeks, 1966:339).

(ii) Northwick Park Hospital: Medical planning concept

Established as an 800-bed district general hospital (DGH), Northwick Park was one of the first built NHS hospitals that intentionally integrated theoretical approaches into its hospital’s medical planning (Weeks, 1963-4:90). Weeks’ concern for constant spatial change was central to this approach:

> The problem is that of sheltering an organisation which has a rate of growth and change which is so great that it makes its buildings obsolescent before they decay naturally (Weeks, 1963-4:85).

Acknowledging this hospital design complexity, Weeks adapted a different approach for each scale of the hospital design (1:500, 1:200 and 1:50). Using modernists Alison and Peter Smithson's city planning theories 'of permanence and transience', Weeks applied his 'indeterminate' architectural tenets - separation of major traffic routes, differential expansion, interchangeability and directions of expansion - to the strategic medical planning (1:500) of Northwick Park. This strategy reinforced Weeks' theoretical principle that a hospital with an indeterminate brief cannot adhere to a finite geometric control system (Weeks, 1963-4:90; 1966:338). Years later, Weeks re-emphasised this principle:

> Since any pre-determined program of space allocations for a hospital can be only a starting point in the long life of a hospital, 'the more carefully the building is tailored to its program, the more certain it is to need alteration and additions very quickly' (Architectural Record, 1970:101).

This specific medical planning principle is central to the thesis concerns of bespoke PFI NHS acute hospitals.

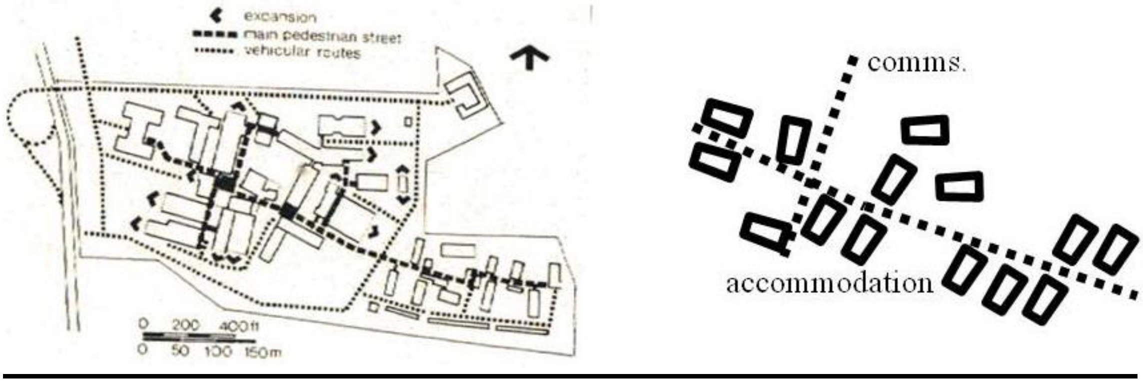


Figure 2.6 Left: Masterplan of Northwick Park (Weeks, 1966:338-9). **Right:** Author's 1:500 medical planning sketch.

Weeks' flexible design principles were expressed architecturally in Northwick Park's medical planning masterplan as two defining elements: (i) a longitudinal indeterminate corridor system; (ii) separate buildings connected along the spine (see Figure 2.6;

Appendix B.3-4). Similar to Renkioi's railway circulation route that transported wounded soldiers directly from the harbour to the door of their wards, Northwick Park's conceptual street layout was:

> The key to the comprehensibility of the building. The mobility of an indeterminate hospital is dependent on the ease with which its building components can be altered around the permanent (Weeks, 1963-4:88; 1966:338).

Runing indeterminately throughout the campus-styled building, this new 'hospital street' concept standardised all hospital communications (Comms.). The hospital street's width was determined by anticipated footfall calculations. The establishment of a communications strategy was followed by the assignment of functional activity to individual buildings situated along the 'hospital street'. Buildings were located as per functional and spatial requirements over numerous floors which deviated from the then popular vertical hospital typology which located functionality horizontally (see section 4.3.2). Positions of functional occupation were designated to achieve maximum departmental and clinical adjacencies. Weeks' approach was driven deliberately by the principle that 'the design process is, in essence, similar in town planning' (Weeks, 1966:338). Consequently, detailed design was not incorporated from the outset of the hospital project. Thereafter, each building was designated one department only where each could extend freely away from the hospital street (Weeks, 1966:338). In the light of rapid change, Weeks argued that the 1:500 strategic medical planning should follow indeterminate principles:

> It all depends on the frequency of change and how 'convenience' is costed....Concepts of treatment and patient care are now subject to quite rapid, major changes which will undoubtedly continue in the future at an accelerated pace...to the point where gross misfit of function and building is intolerable (Howard, 1972:255).

In response, Weeks applied his 'duffel coat' principles to the 1:200 internal medical planning of Northwick Park (see Table 2.3). How this was achieved architecturally lends itself to Aalto's strategy of separation. Each building and its clinical functionality were free to flexibly expand independently at different rates:

> It was in the nature of the indeterminate program that the buildings be designed as individual houses for departments. That way, the growth rate of each could respond to later input independently (Architectural Record, 170:102).

Weeks applied his ‘duffel coat’ principles through four formatted categories where each department was assigned to a category at the project outset.

Weeks *Duffel Coat* theories
1. No need for physical alteration to the building.
2. Departmental expansion to be measured by number of room changes.
3. Whole new complete buildings for whole new departmental ‘communities’.

Table 2.3 Weeks *Duffel Coat* medical planning theories for expansion (Weeks, 1963-4:91).

The first category was assigned to hospital disciplines with high growth expectation. These departments were allocated to buildings of indeterminate increments designed to be open-ended for external departmental expansion. Departmental growth was calculated upon clinical projections, such as, increased patient numbers and treatments, resulting from new and upgraded medical technologies. Departments assigned to this category included diagnostics (such as Imaging), Out-patients (OPD) and A&E. The second category related to the standardisation of internal departmental expansion only. ‘Loose-fitting shells with internal subdivisions capable of adjustment’ were allocated to departments where change may occur without the requirement for additional area (Howard, 1972:254). For example:

> In certain departments – such as laboratories – changes are likely to be internal without a strong likelihood of increase in size. Structures for such departments then are required to have internal flexibility in a fairly fixed envelope (Architectural Record, 170:102).

The third category was for departments that required complete extra buildings. These departments were allocated new freestanding buildings within the original 1:500 masterplan (Howard, 1972:254). Such departments included in-patient wards which, as an outcome of increased OPD patients, would require additional overnight space for elective procedure recoveries. The fourth category was for departments with no foreseen future changes or expansion. These included non-clinical areas, such as, Chapel and Dining facilities. In this case, predictions proved incorrect as Dining was enlarged at a later stage (Howard, 1972:254). Therefore, consideration for worst-case scenarios for all departments must be accounted for by implementing flexible medical planning solutions.

Thirty years later, Weeks reasserted that Northwick Park's durability was 'purposely designed to allow for unspecific change' (Weeks, 1999:15). Weeks' reference to small changes undertaken for clinical research staff confirmed the hospital building's success at adapting to change and growth. A new facility was completed, which relocated a front door, but was built without disruption to existing facilities (Weeks, 1999:15). Additionally, Weeks mentions a scattering of reconfigured internal space:

> The buildings have proved able to adapt well to the internal re-planning needed over the life of the buildings (Smyth et. al., 2006:41).

No formal medical planning observations have been recorded about these alterations. However, while Weeks' open-endedness was never fully tested, overall he argues that Northwick Park remains a successful hospital masterplan (Weeks, 1999:16). The hospital's durability against time confirms the success of Weeks' medical planning principles. Furthermore, recent evidence to support this achievement has appeared in the form of a proposed new A&E building (2012). Witnessed by the author, a new A&E block will be added to the original masterplan but the hospital's strategic medical planning will remain unchanged once the new A&E is operational. This outcome will execute the continuation of a successful flexible design solution. Hence, the thesis identifies separated functionality as essential to current medical planning practice.

Built during the first and last national NHS hospital building programme, Northwick Park acts as a precedent for current PFI NHS hospitals. As an urban acute hospital in

London, Northwick Park's separate building concept established a medical planning strategy that avoided 'a building that would be the optimum fit for specific requirements over a given time' (Spring, 1979:54). Instead, Northwick Park gave way to a sensible architectural solution capable of flexibility and adaptability. In the long-term, Northwick Park reflected 'classic concepts of the 1960s'. These being 'high technology, economy of scale, flexibility for growth and change' are not dissimilar from current medical planning practice (Spring, 1979:54). However, the building was delivered over budget resulting in its approach being criticised by the 1980s. Its popularity declined after the 1970s economic crisis being superseded by the NHS's 'Nucleus' type typology (see section 4.3.4). This 'low-key' and 'small-scaled' horizontal typology was derived from Le Corbusier's unrealised Ospedale Civile. The medical planning background to this horizontal typology type is explored next as a flexible medical planning solution.

2.1.3 Ospedale Civile, Italy (1964-66), Le Corbusier.

Le Corbusier's Ospedale Civile is an unrealised late-20th century hospital project which contrasts radically with avant-garde hospital design at that time. Ospedale Civile's medical planning strategies are explored from the perspective of designing an acute hospital on a dense urban site. Additionally, this section explores the Ospedale Civile as a precedent to the NHS's Nucleus typology which, as a hospital type, was replaced by many PFI NHS hospitals.

(i) Background to Ospedale Civile

The financial climate post World War I and II devastated construction activity. The main architectural activity was intellectual in the absence of commissionable work (Copplestone, 1991:20). Le Corbusier and other architects availed of this time to test and publish novel ideologies that revolutionised 20th century architecture. Post-1950s, the financial and social effects of World War II demanded new and alternative approaches to modern architecture that responded to ‘recurring calls for efficiency in land use, indeterminacy in size and shape, flexibility in building use, and mixture in program’ (Sarkis, 2001:13). A mat-building type typology evolved which architect Alison Smithson defines in *How to Recognise and Read Mat-building Mainstream Architecture as It Has Developed* (1974):

> Mat-building can be said to epitomize the anonymous collective; where the functions come to enrich the fabric and the individual gains new freedoms of action through a...close knit pattern of association and possibilities for growth, diminution and change (Smithson, 2001:91).

Transferring Smithson’s theory into ‘a series of architectural objectives’, architect Stan Allen summarises mat-buildings:

> A shallow but dense section, activated by ramps and double-height voids; the unifying capacity of the large open roof; a site strategy that lets the city flow through the project; a delicate interplay of repetition and variation; the incorporation of time as an active variable in urban architecture (Allen, 2001:121).

Generally, a mat-building’s architectural form is of low-rise and high-density, homogeneous in its layout and consists of a systematic repetition (Sarkis, 2001:14).

While the emergence of mat-buildings inspired Le Corbusier to develop his own mat-building principles, it was from Northwick Park that Le Corbusier saw an architectural precedent for urban hospital design: it embodied mat-building principles insofar that ‘the architect can design the system, but cannot expect to control all of the individual parts’ (Allen, 2001:122). Similarly, Le Corbusier took inspiration from Weeks’ indeterminate architecture by designing extendable ends that allowed for any form to be freely added to an indeterminate ‘hospital street’ (Howard, 1972:254). These background events influenced Le Corbusier’s design of Ospedale Civile.

(ii) Medical planning of the Ospedale Civile

Le Corbusier’s strategic medical planning for the Ospedale Civile was a low-rise horizontal typology over three floors (see Figure 2.7). This ‘campus’ typology included ‘a 16-room hotel’ and was sized to a human scale:

> The hospital organisation should be broken down into small, self-contained units in which doctors, nurses and patients can readily feel their identity (Interbuild, 1965:10).

The medical planning strategy assigned one user group to each floor, such as, out-patients, staff or in-patients. The outcome located activities with large public footfalls at ground floor, staff and treatment activities at the next level, leaving the quieter patient areas to be located at the highest building levels (see Appendix B.5-6). As ‘the hospital is entirely for intensivecare patients, this strategic clinical arrangement was a highly appropriate arrangement’ but Le Corbusier’s enclosed and viewless single patient bedrooms were inappropriate within the realms of contemporary holistic hospital design (Barnett, 1966:193). However, this design decision was driven directly by distinct site characteristics: the proximity to the Railway Terminal and nearby industrial squalor of Mestre (Colquhoun, 1966:221).

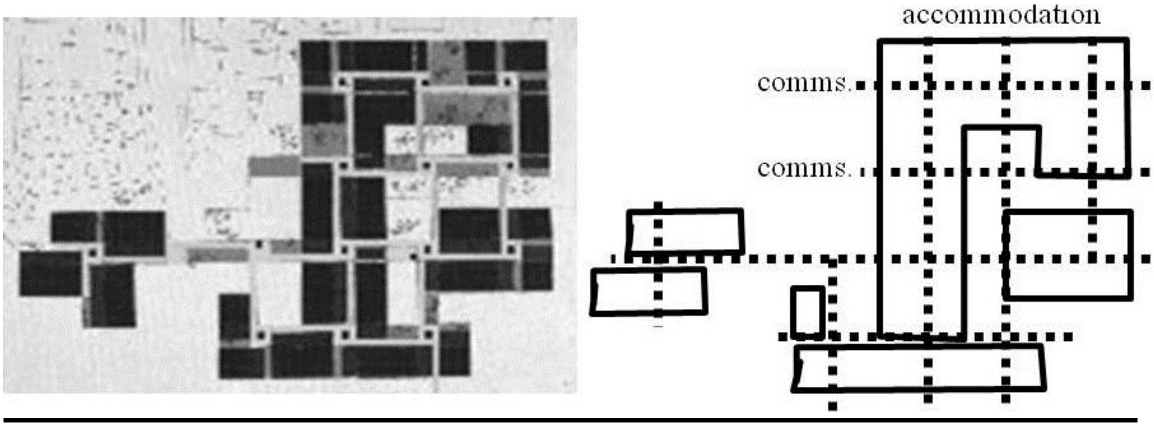


Figure 2.7 Left: Masterplan Ospedale Civile (Sarkis, 2001). **Right:** Author’s 1:500 medical planning sketch.

By medical planning standards, Ospedale Civile’s conceptual strategy was not unusual for the organisation of hospital functionality as it reflected the then latest ‘match-box-on-a-muffin’ vertical hospital design model (see section 4.3.2). The arrangement of this model fundamentally locates all clinical functionality within a podium while a ward tower block is located on top of diagnostic and treatment (D&T) departments. In the case of Ospedale Civile, the patient ward areas were horizontally distributed to form, what the thesis describes, a horizontal matchbox of architectural articulation. This feature, a strong representation of Le Corbusier's mat-building theories, was part of his alternative medical planning solution for Ospedale Civile's future flexibility.

Le Corbusier employed two approaches to flexibility. Similar to Weeks, each strategy was assigned to different scales of design. Le Corbusier's first strategy enabled spatial flexibility at the 1:500 medical planning level. Through the segregation of the brief's functionalities onto separate hospital floors, potential re-planning could be 'combined and recombined in groups' around vertical cores of circulation (Sarkis, 2001:85). This solution reflects current medical planning practice in the use of flexible hard and soft spaces that allow for the adaptability of internal spatial expansion and contraction (see section 3.5). However, Le Corbusier's endeavour towards flexibility was further influenced by prominent 1960s theoretical practice where a new process of achieving spatial flexibility was introduced through the recently identified relationship between flexibility and briefing:

> Flexibility became a highly desirable quality in modern architecture, just as programming was getting established as a scientific means for achieving specificity and efficiency in the definition and use of space. This scientific approach to functional specificity was linked paradoxically to spatial flexibility (Sarkis, 2001:81-2).

For hospitals, the application of programming[3] became an important feature of hospital design:

> Demographic changes coupled with improvements in medicine required the construction of more hospitals with rapidly changing needs and unpredictable growth (Sarkis, 2001:83).

---

[3] Programming is the American terminology for the British medical planning terminology for 'briefing' and was mythically derived from post WWII downsizing of military bases.

Flexibility became central to modern architecture, and specifically for hospital design, as architect Hashim Sarkis argues, it 'accounted for the margin of error in the relationship between form and function' (Sarkis, 2001:82). Similarly in the UK, where time and money was scarce, there were 'many forms of experimentation in pursuit of flexibility: employing efficient programming of facilities to produce multi-purpose space' (Sarkis, 2001:83). Driven by industrial mass production, the process of briefing was to create flexible efficient universal spaces. With regards to Ospedale Civile and its ability to respond to future change, Sarkis argues:

> Le Corbusier was well aware of the different positions on program and flexibility... arguing that advances in the field (medicine) call for a complete reconsideration of the layout of the hospital and even its role as an institution (Sarkis, 2001:85).

Upon this premise and Northwick Park's philosophy, Le Corbusier embodied his own mat-building principles to establish a flexible strategy:

> Buildings transform into a series of networks themselves, and that these networks acquire their shape from an external rather than a programmatic source (Sarkis, 2001:85).

Therefore, Le Corbusier's strategic medical planning approach for an urban context was not restricted by hospital brief or site boundaries. Instead, he proposed a principle of organic flexibility which blurred the boundaries between hospital building and city form. For example, all hospital corridors and courtyards extended to the surrounding streets and open spaces (see Figure 2.7). This was the basis for Le Corbusier's second approach to flexibility: a co-extensive architecture for urban acute hospital design.

The remarkable feature of the Ospedale Civile concerns the building's area footprint. It unusually extended horizontally over 70,00sqm which was a radical departure from the then popular vertical typology (Pica, 1965:8). Le Corbusier created this alternative solution in response to its adjacent low rise and dense medieval urban fabric. Equally, he considered mat-building objectives to respond to spatial efficiency concerns. In response to these conditions, Le Corbusier's approach was to embrace medical planning flexibility at an urban scale (1:1000) which, in vertical typologies, was restricted predominantly to hospital podium levels only. Theoretically, Le Corbusier was testing the concept of spatial flexibility and efficiency through lateral organisation not too dissimilar from contemporary architect Ken Yeang's sustainable 'landscrapers' (Yeang, 2008). At that time, Le Corbusier's proposed machine for healing was considered 'radical', 'open-minded and courageous' which, undoubtedly, the Ospedale Civile offered as an option for future flexible hospital design (Pica, 1965:8). These theories were, however, adopted unsuccessfully in the NHS's Nucleus horizontal type typology. The failure of this model is explored in section 4.3.4's historical context of NHS hospital space.

While never realised, the Ospedale Civile conjures an architectural discourse that injects conceptual thought into alternative medical planning solutions for complex urban acute hospitals. This study explores Le Corbusier's optional solution in the face of empirical knowledge rising from the thesis case study and medical ET research (see Chapter 8).

2.1.4 Summary

This section set out to explore the fundamentals of flexible hospital medical planning by assessing the factors contributing to long hospital building life-spans. Section findings from the taxonomy of 20th century typologies are summarised in Table 2.4. Overall, the thesis identifies three medical planning principles for flexible hospital design.

The first principle is indeterminate hospital designs that can be approached in different manners. It was shown that each architect formed his own principles, such as, co-extensive or indeterminate architecture, drawing from historical precedents of Zonnestraal, Renkioi and Northwick Park. Notably, each architect's theory was underpinned by one core principle: indeterminate design solutions are essential for creating sustainable hospitals with future unknowns.

	Hospital type	**Medical Planning Solutions**			**Flexibility**
		1:500	**1:200**	**Standardisation**	
Aalto	Competition - Healthcare building programme	Separation of functionality		Decentralised and patient-orientated standardisation	Yes
Weeks	NHS 10 year building programme	'Indeterminate Architecture'	Duffel coat theories	'Indeterminate Architecture' & 'duffel coat theories'	Yes but not fully tested
Le Corbusier	Conceptual project	Co-extensive architecture	Functional separation, hard and soft spaces	Mat-building theories	Theoretically as not tested

Table 2.4 Summary of section 2.1, Theoretical Framework: Medical planning of hospitals.

The second principle identified is functional separation which is underpinned by an acknowledged state of ongoing evolving medical demands. Aalto and Weeks both assigned different functionalities to individual buildings while Le Corbusier's horizontal floor solution dealt with functional separation within an urban context. The design of functional separation was delivered at different scales of medical planning. For example, Weeks' 1:500 medical planning strategy consisted of individual blocks along a hospital street while Le Corbusier incorporated soft and hard spaces to deliver adaptability at 1:200 and 1:50 scales.

The third principle is standardisation which can be achieved through different methods. Aalto's decentralised human-centred standardisation was articulated at the 1:50 scale. Alternatively, Le Corbusier's approach was delivered through his own set of mat-building principles while Weeks incorporated his 'duffel coat' strategies to enable a loose form of standardisation. Collectively, all medical planning principles were intended to achieve an architectural flexibility that would provide sustainable hospital building life-spans.

Unanimously, one principle dominates throughout all explored typologies: flexibility is essential to the future-proofing of hospital buildings. In the face of future technological change, medical planners are advised to:

> Plan their buildings so as to render them suitable not only to the present well-defined needs, but readily adaptable to meet new and ever-changing requirements (Kelly, 1934:33).

This finding contributes to the gap in knowledge that defines the principles required to future-proof 21st century urban acute hospitals.

2.2 Contextual Framework: Hospital medical planning

By 2000, existing NHS hospitals were struggling to adapt to evolving healthcare demands driven by population growth, demographic shifts, increased human life-span and improved medical practices. In response, extensive UK hospital re-construction was needed desperately. Testament to this was the NHS's estate status which was past refurbishment by the 1990s (Leach, 2007:22). The *NHS Plan 2000* was introduced by the then Labour government to reconstruct its ailing estate. Capital investment to deliver this ambitious hospital re-building programme was, however, unavailable. The financial solution was resolved through a PFI process which has produced some of the world's largest, sophisticated hospitals. Nevertheless, apprehension about the quality of 'state-of-the-art' PFI NHS hospitals is expressed constantly by professionals (Diamond, 2006:42). To understand their anxieties, three medical planning deficiencies involved with creating PFI NHS hospitals are examined:

2.2.2 Current status of medical planning profession

2.2.3 Current medical planning design model

2.2.4 Design process of PFI NHS acute hospitals

Additionally, one factor underpins this contextual framework: a lack of information regarding future medical technology and its spatial requirements (Francis et. al., 1999:25). This lacuna in the knowledge of medical planning is described, illustrating how this deficiency is affecting the design of NHS hospitals negatively. Prior to this discussion, a brief context to the fundamentals of medical planning is provided.

2.2.1 Defining medical planning: Building blocks

Medical planning is the design process which forms hospital typologies and their internal spatial design. This process is divided into a three-tier structure that resembles a biological one – system, organ and cell (see Figure 2.8).

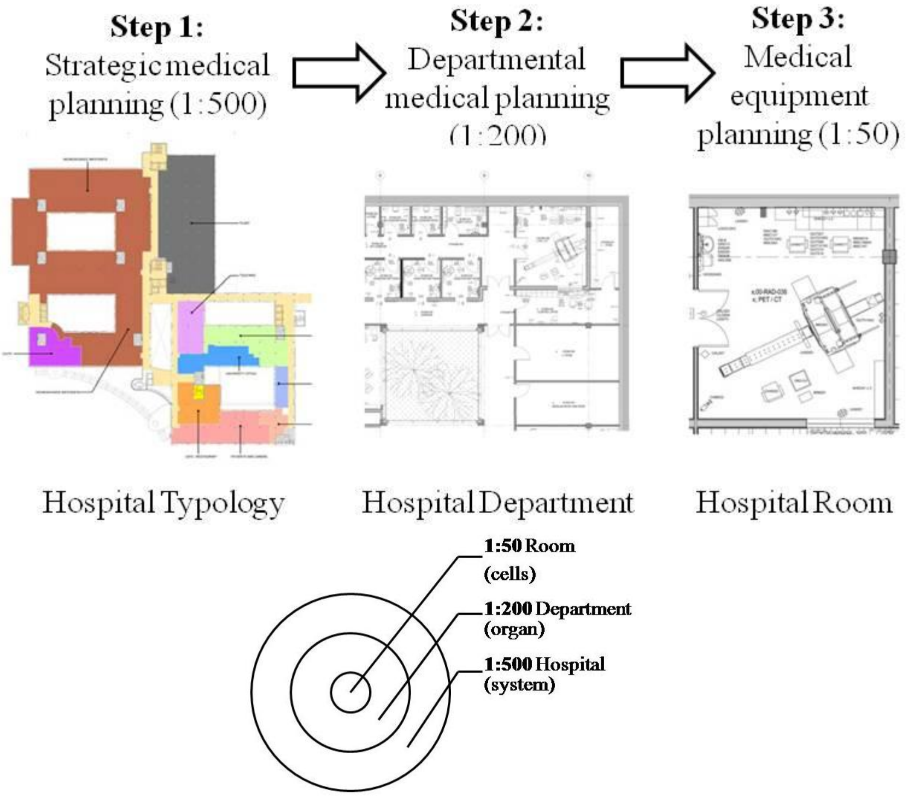


Figure 2.8 Above: Step-by-step medical planning process (Plans of Oxford Radcliffe, RTKL Architects). **Below:** Author's graphical analysis of medical planning tiered structure.

The medical planning process usually begins at the strategic level of architectural organisation – the system (scale 1:500). However, quality design at the system scale is only achievable through a complete understanding of all medical planning procedures especially the spatial planning for medical equipment - the cells (scale 1:50). This understanding, based upon the author's experience, is vital for the realisation of medical planning requirements at all levels. For example, a hospital with a large number of in-patient bedrooms produces a particular typology due to the necessity for perimeter walls, access to direct daylight and fixed spatial dimensions for functionality and equipment within each patient room (Kelly, 1934:33-35). Should the design brief demand all patient bedrooms to be single occupancy and same-handed, this too will produce a particular typology. Without this foresight at the cellular level, incorrect strategic medical planning decisions are taken that result in inaccurate building footprints and poor 1:200 departmental medical planning (the organ).

Medical planning is based upon a quantitative analysis of hospital functionality where every function is converted into a measured spatial entity. In the UK, spatial data is calculated and distributed through HBN guidance (Department of Health, 1992-2010). Incorporated into NHS hospital designs since 1961, HBN guidance is structured upon mid-20th century architectural theories. Over the past decade, medical planning under the PFI process has been forced to strictly adhere to HBN spatial standards. Negative repercussions from this outcome are described in the following sections.

2.2.2 Current status of medical planning profession

Medical planners are the professionals responsible for the medical planning of hospitals. Their expertise involves in-depth knowledge concerning not only hospital design but the whole healthcare industry. This knowledge ranges from financial forecasting and environmental impact assessments, to the latest robotic laparoscopic technology or post-operative evaluation (POE) data for the design of neo-natal intensive care units (NICUs). Therefore, to create ‘state-of-the-art’ hospital environments that support the delivery of clinical excellence, it is critical that medical planners are aware of cutting-edge healthcare information. However, due to enormous workloads and insufficient research time, medical planners rely upon other DTM professionals to source future healthcare and technological knowledge. This reliance on second-hand information is deficient and limits design innovation for future healthcare environments. Inadequate awareness of future needs weakens the design of sustainable hospitals.

2.2.3 Current medical planning design model

Three contributing factors illustrate the context surrounding the current medical planning model's status.

The first contributing factor is the inheritance of the NHS's inflexible Nucleus model which dominated British hospital design between 1980-2000. The negative affects of Nucleus hospitals upon functionality, flexibility and the health of its occupants, began emerging in the 1990s. Even the NHS acknowledged the flaws in these hospitals stating that the Nucleus model had reduced:

> Fitness for purpose and the potential for flexibility; and – a lack of future-proofing – capacity for extension, ease of adaption and future flexibility (Diamond, 2006:5).

Even though concerns about the Nucleus model were recognised widely prior to 2000, no HDR or modifications to the existing design model were implemented prior to the *NHS Plan 2000*. Unlike the Modernists of the 1920s, the absence of innovative research prior to the PFI process resulted in medical planners inheriting Nucleus strategies structured on an old hospital design paradigm. While the Nucleus model no longer dominates NHS hospital design, the current model - a variation upon this theme - remains poorly suited to 21st century healthcare delivery (see section 4.3.5). As healthcare architect Lawrence Nield suggests of contemporary hospital design:

> It seems that when people set out to design a hospital they seek to improve the existing model or type, rather than question it (Nield, 2008: 255).

Briefly, a new hospital design model is required for 21st century healthcare demands to eliminate the negative reputations associated with PFI NHS design.

The second contributing factor is the lack of specifically related NHS HDR that focuses on medical technology and its spatial implications. At present, British DTMs rely upon American research which is based upon different models of care, epidemiological patient data and financial management schemes. As a result, quantitative American data cannot be applied directly to the NHS healthcare system. For example, statistical data relating to patient admissions distorts the local needs of clinical services and spaces. In spite of discrepancies, American research continues to be used within British medical planning models. This may respond differently to local needs which the author believes may potentially undermine the longterm sustainability of hospitals.

The third contributing factor is the delivery of PFI NHS hospitals. Briefly, medical planning under PFI strictly adheres to NHS HBN guidance. Based upon first-hand experience of designing ‘state-of-the-art’ PFI NHS hospitals, the author questions the robustness of current NHS HBN guidance. A particular cause for concern is the lack of consideration for future medical ETs. For example, while HBN guidance is researched thoroughly, one factor remains consistent: quantitative calculations for spatial data are based upon current, not future, technologies. As ETs are expected to radically change life styles and specifically medicine, the author questions whether ‘state-of-the-art’ PFI NHS hospitals will cope spatially with the implementation of medical ETs. While HBN guidance is lauded as the world’s most extensive data for healthcare design, information regarding medical ETs is documented insufficiently within current HBN guidance (Hignett et. al., 2007:1). Exemplifying this is HBN10-02’s document *Surgery Health Building Note 10-02: Day surgery facilities*:

> Imaging
> 1.15 Increasingly, imaging is part of the surgical procedure. Existing theatre technology, involving TV cameras, ultrasound and X-ray fluoroscopy, is also developing rapidly.
>
> 1.16 Changes in imaging practice will impact on theatre space and other requirements in a DSU and should be considered at planning stage (DHEFD, 2007:2).

Such vagueness illustrates why medical planners lack awareness of ET knowledge but is this sufficient basis for designing an estate worth over £25 billion of tax payers' money? In fact, researcher Peter Scher[4], commenting on the analysis of HBN schedule of accommodations (SOAs), argues that 'information for design in the NHS is in a hopeless muddle' (Scher, 2006:38). Additionally:

> Other than research in the 1950s (Nuffield Provincial Trust, 1955) very little peer-reviewed empirical research has been published as an evidence base for the HBN guidance (Hignett et. al., 2007:1).

Such declarations support this study's concern that insufficient information exists within HBN guidance, particularly of data linking space and future technological change, which justifies this study's necessity.

2.2.4 Design process of PFI NHS acute hospitals

Writing in *Hospital Development* about the status of the NHS's estate infrastructure, health service planning consultant John Leach discussed:

> In the pre-PFI setting...the extent to which the NHS estate had been allowed to deteriorate, with billions of pounds of 'backlog maintenance' due to the systematic failure of NHS authorities to look after their buildings (Leach, 2007:22).

In response, the *NHS Plan 2000* was initiated to build 111 new UK hospitals by 2010. Of these, the majority of acute PFI hospitals are bound contractually to a functional expectation of 35-40 years[5] (Wanless et al., 2007:116). Setting this time frame as the lifespan for PFI NHS acute hospital buildings, this study questions whether these 'state-

---

[4] Peter Scher, researcher at MARU, South Bank University, UK.

[5] As per contractual agreements under PFI, each hospital Trust enters an agreement with a Consortium to rent the hospital building to the Trust. In general, agreements are structured between 35-40 years but depend upon individual terms and conditions of PFI contractual agreements.

of-the-art' hospitals will perform efficiently throughout their contractual term. This is astonishingly short in comparison with some Victorian hospitals still in operation and is one reason for doubting the performance longevity of PFI hospitals. Two other major medical planning issues relate to the thesis' PFI concerns.

(i) PFI process

Recent NHS hospital construction has been procured through numerous methods, such as, traditional and design and build (D&B). Post-1995, the preferred method for reconstructing acute hospitals under the *NHS Plan 2000* was PFI. All procurement methods contain negative attributes as complications associated with building hospitals are not explicit to PFI. However, one differential disadvantage resulting from PFI contractual legalities is increased financial risk for consortia[6]. Higher exposure to financial loss drives PFI consortia to impose what this thesis considers is a detrimental medical planning policy; concisely defined spatial specifications embed an architectural restrictiveness that contradicts more efficacious flexible design approaches to sustaining hospital space. While spatial problems likely to arise from PFI processes will reflect similar shortcomings from other methods, the thesis strongly argues that PFI processional requirements will exaggerate future negative spatial outcomes. For example, in the PFI process, consortia will not spend money on space that is not briefed. Consequently, the size of hospital spaces is calculated forcibly to fractions of millimetres. This policy favours reduced capital investment over sustainable quality design. This process creates cost-driven rigid hospitals that will become financially expensive to Trusts in the long run when inflexible HBN driven spaces will need to be constantly refurbished. This negative consortia method is further aggravated by a lack of financial foresight from Trusts:

---

[6] See Glossary.

> Health chiefs and their private-sector backers are reluctant to take the financial risks that are associated with producing better designed and innovative hospital buildings through PFI contracts (Booth, 2000:16).

Critic Robert Booth argues that earlier PFI schemes were ‘taken off-the-shelf’ and ‘simply failed to rethink hospitals’ design needs’ (Booth, 2000:16). So poor is the process that Unison, the UK’s largest public sector union (2009), has called for PFI to be scrapped completely (Rogers, 2009:5). In the same *Building Design* article, architect Richard Rogers concurs with Unison’s argument, demanding that the government should scrap PFI. Unfortunately, as long as government funding remains unavailable, the PFI process looks set to continue indefinitely.

It is felt that current designs are not designed to deal with ongoing NHS organisational shifts, as critic Damien Arnold argues:

> An examination of new policy since 2002 alone demonstrates the rate of change...The PFI process needs an overhaul to give trusts sufficient flexibility to build future-proof hospitals that can adapt to healthcare changes (Arnold, 2004:7).

As the cause for rigid design is primarily driven by PFI consortia costs, the benefits of HDR to create a new flexible design model should have been undertaken before the PFI process commenced. Instead, as Simon Foxell of the NHS Confederation argues:

> We are now reaping the consequences of not having done this in early PFI projects and are having to modify and change what has been built (Arnold, 2004:7).

This is hardly the vision anticipated by Griffin & Roughan’s concept for flexibility. However, adapting to change is not unique to PFI hospitals as Weeks argued long before:

> To accommodate growth and change in hospital design....hospital buildings must be designed on the assumption that, in the long run, the brief is wrong (Weeks, 1963-4:90; Spring, 1979:54).

While PFI hospitals are designed intentionally to be flexible, the reality of this contradictory process is the creation of bespoke rigid architectural hospital solutions. This unsuitable outcome leaves the medical planning design model under PFI questionable. This concern is enhanced further by the underlying terms of upgrading technologies within PFI contracts. NHS Trusts will encounter additional costs for installing new technologies and associated environments. Therefore, in contemplating the NHS's 'affordability' concerns, it is crucial that spaces respond to technology changes to eliminate the financial burdens of reconstructing unsustainable hospitals.

(ii) Lack of technology information for medical planners

From my perspective as a medical planner, the transfer of technological information within the PFI process is weak. For example, all design requirements for PFI hospital projects are issued via Trust briefing documents. Currently, these reports do not include information concerning medical ETs. This thesis anticipates this failure of communication to cause long-term spatial design issues. Problems originate from two main sources within the PFI process.

First, during the PFI process, medical and health planners collaborate to create SOAs that are architecturally, clinically and financially achievable. This involves health planners advising medical planners of clinical procedures, hospital management and healthcare policies. Medical planners inform health planners of architectural requirements, spatial benefits and restrictions. Combined, all discussions transform a Trust's vision into an affordable hospital typology. Therefore, for the production of appropriate SOAs, planners must receive sufficient information. In 2004, this was not the case as 'architects were still not being briefed well enough by NHS clients' (Arnold, 2004:7). By 2012, some progress has been achieved but the dispersal of insufficient project information remains common practice. As a medical planner, this status is completely unsatisfactory. For example, standard practice within current PFI projects is to over-size high-spec rooms. This strategy is based on a historical trend of 20th century technology equipment development. However, the thesis questions: if the future of technology is nanotechnology (one of smaller matter), is the creation of larger rooms the correct solution for future acute hospitals? This question is central to the study's main research and demands essential exploration within Chapters 5 and 7.

The second source of long-term design problems relates to a Trust's Technological Operational Policy (TOP) document. Dispersed through Trust documents, data is either not detailed enough or, in most cases, not issued at all (Barlow & Koberle-Gaiser, 2008:1397). Technological information, a critical factor for understanding future spatial needs, is not offered within the PFI process:

> It is apparent that a number of the problems faced by Trusts are due to the fact that equipment services are not given early enough consideration within the PFI process (DOH, 2005:1).

In response, the DOH amended their PFI documentation detailing how Trusts must adhere to procedures during PFI bid processes (see Appendix B.7-8). However, documents remain insufficient as sources of technical information for medical planners. This gap in knowledge diminishes the creation of a new resilient medical planning design model. Therefore, to reduce negative implications for future hospital designs, it is imperative that medical planners receive detailed TOPs for all hospital projects.

2.2.5 Summary

This section has advanced the understanding behind current medical planning concerns. While universal, most problems have been exaggerated under the PFI process. In summarising the outcome of PFI hospitals, even the NHS state:

> Despite these levels of investment, many of the new hospitals have not met expectations for a step change in quality and innovation in design and clinical solutions (Diamond, 2006:1).

Driven by numerous factors, of which, many are linked by a lack of information, this study stresses the need for all medical planning areas to be revisited and reformed.

2.3 Theoretical framework: Technologies

The theoretical framework for technologies is informed by four scientific works. These are broken into two categories of technology and medical ETs. The first section explores and identifies the scientific theories of Feynman and Moore. Both individual works define the fundamentals of current technology which underpin the theoretical framework for medical ETs. This is followed by an examination of medical ETs which is informed by works from computer scientist Ray Kurzweil and physicist Robert Freitas Jr.. Both latter scientists visualise the potential for medical ETs and its broad spectrum of future medical possibilities. Works by Kurzweil and Freitas are formed upon the scientific theories of Moore and Feynman. To begin, a brief background defines the history and future projection of technology development to understand why the current evolving rate of technologies is a concern for hospitals. This forms the framework for this study's technological research within the context of exploring hospital space development.

2.3.1 Background to technology development

Rates of technology development are informed by works from Kaku and business writer Alvin Toffler which contribute to understanding 19th-20th century technology progressions explored in Part II. Their works offer alternative historical perspectives that converge to a single principle: major technological progression is forecast.

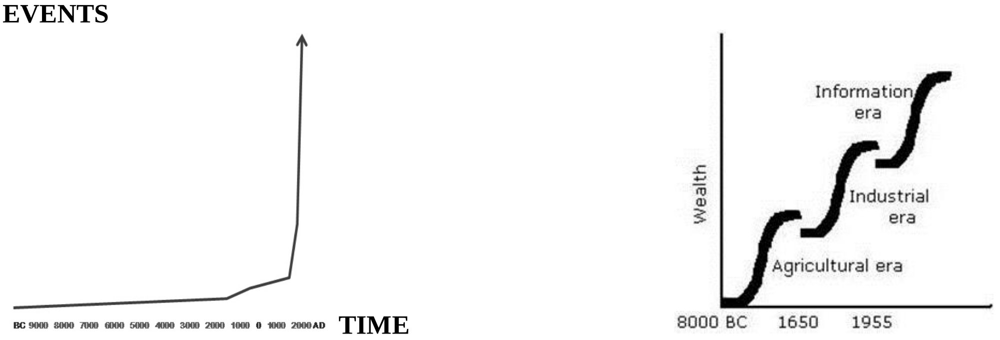


Figure 2.9 Left: Graphed analyses events and time of technological progression. **Right:** Toffler's 'waves of change' (Maaw, 2010).

Technology has progressed over thousands of years through man's ability to create tools which Toffler maps from the perspective of the history of civilisation. Toffler quantifies all social and economic events to establish technology's current and future growth rate (Toffler, 1980:20). Graphed data indicates an exponential rate of change has occurred particularly since 1600AD. Toffler categorises these findings into three periods of time known as 'waves of changes' (see Figure 2.9). This is based on 'a succession of rolling waves of change' where each wave 'identifies key change patterns as they emerge' (see Table 2.5; Appendix B.9-10) (Toffler, 1980:29).

Wave of change	Principle Theory
First	Pre-17th century culture that evolved hunting societies into settled agrarian communities.
Second	300 year period, commencing from mid-17th century. Technological development of this Industrial Age transformed cultures into mass producing and industrial societies.
Third	The Information or Scientific Age is the current wave of change (+1950s). Dominated by computer technology, communications and data. For the first time white-collar and service workers out number blue-collar workers, United States of America (USA).

Table 2.5 Toffler: Three 'waves of change' (Toffler, 1980:26-9,37-52).

From this 'social wave front analysis', Toffler identifies that the current status of technology is embarking on a 'third wave of change'. This development is driven by computer technology advancements that emerged after 1950 (Toffler, 1970:386). The thesis summarises the significance of Toffler's principles: (i) technology growth has evolved radically since 1600; (ii) the 'third wave of change' has only begun to experience current technology's full capacity.

Alternatively, Kaku offers his theory for technology progression from a quantum physics perspective. Kaku's *Three Revolutions* attributes all pre-2000 technology progression as an era whereby:

> The Age of Discovery in science is coming to a close, opening up an Age of Mastery (Kaku, 1998:404,5).

This theory is supported by the principle that 19th century progression was ‘a period of intense scientific discovery’ while the 20th century discovered ‘the basic laws of matter, life and computation’ (Kaku, 1998:4). Amalgamated, both centuries’ scientific discoveries allowed for all matter and life to be understood. This was achieved through three technological developments which are the founding components of medical ETs: Quantum, Computer and Biomolecular Revolutions.

The first ‘Quantum’ revolution began with the discovery of the Standard Model of quantum theory (1925). Scientists could finally ‘predict the properties of everything from tiny subatomic quarks to giant supernovas in outer space’ (Kaku, 1998:8). With the mechanics of matter defined, the ‘Quantum’ revolution progresses presently with the development of creating matter. For example, the discovery of deoxyribonucleic acid (DNA) molecules (1953) allowed for the detection of cancerous tumours. Today, research is focused on discovering a cure for this terminal disease which Kaku believes will arrive by 2020 (Kaku, 1998:172).

The second ‘Computer’ revolution commenced with the invention of the transistor by Bell Laboratories, 1948 (Kaku, 1998:8). This discovery was a defining turning point in technology’s history. Since then, technology has evolved exponentially using ‘quantum mechanical devices’ to develop home computing by the 1980s and the internet a decade later. However, Kaku anticipates the next ‘Computer’ phenomenon to be ubiquitous computerisation (Kaku, 1998:8). Scientifically based, Kaku argues technology will become so affordable, invisible and embedded that intelligence will exist in every object (Kaku, 1998:36). For example, self-driving cars will be developed from ‘smart technologies’ that respond to equally intelligent ‘smart roads’ (Kaku, 1998:38-40). Part of this ‘Computer’ revolution, Kaku anticipates, will be the prominent development of robotics that will understand human language while recognizing objects in the environment (Kaku, 1998:16). Proof of future robotic potential is currently being developed at Massachusetts Institute of Technology's (MIT) Artificial Intelligence (AI) laboratory. Their current focus of technology development is robotic pattern recognition and the ability to understand hearing. Hence, the reality of robotic use by 2020 is gaining momentum for a future where robots will play an essential role in delivering healthcare.

The third 'Biomolecular' revolution began when Nobel winners Watson & Crick (1962) decoded the atomic structure of the DNA molecule (1953). Biomolecular technology has developed greatly to determine all living molecules, such as, the genetic code for the human immunodeficiency virus (HIV) (Macgregor & Poon, 2003:461-7). Anticipations visualise a new paradigm for medicine as Nobel Laureate Walter Gilbert argues:

> The possession of a genetic map and the DNA sequence of a human being will transform medicine (Gilbert, 1998:144).

This will be made possible through the discovery of all genes in the Human Genome Project where biologists borrow tenets from *Moore's Law* to determine the number of DNA sequences doubling every two years (see section 2.3.3). This knowledge will improve biomolecular technology to allow patients' medical history and future to be confirmed:

> By 2020 or 2030...You'll be able to go to a drugstore and get your own DNA sequence on a CD, which you will then analyse at home (Gilbert, 1998:143).

Based on these technology principles, the scope for medical progression is anticipated highly where Gilbert predicts the capabilities of biotechnologies will conquer human illnesses, such as, cancer and diabetes (Kaku, 1998:165-72).

Toffler and Kaku agree upon the phenomenon of post-1950s technological progression. Both share a vision that major potential technology growth is forecast. Furthermore, Kaku argues that his contemporaries' visions should not be ignored as physicists, and not surgeons, are responsible for many medical inventions (Kaku, 1998:6). Such physicists' inventions include x-rays and computer tomography (CT) which radically changed the delivery of 20th century healthcare. Of these, Richard Feynman is a most noted physicist, as his theories revolutionised science and technology . Feynman's theories underpin the fundamentals and progression of medical ETs and are presented next.

2.3.2 Richard Feynman: '*There's Plenty of Room at the Bottom*'

Feynman is regarded as one of the greatest scientists of all time. His theories upon quantum electro-dynamics led to new fields of science and are now applied theoretically in every other science. Significantly, Feynman is responsible for conceptualising the notion of small-scale technology. Originally presented at a dinner speech, Feynman later published his theories in *There's Plenty of Room at the Bottom* (1960) (Yih & Moudgil, 2007:245). Termed later as 'nanotechnology' in Taniguchi's *On the Basic Concept of Nanotechnology*, Feynman's theory visualised technology's potential to have 'an enormous number of technical applications' (Taniguchi, 1974; Feynman, 1960:22). For example, Feynman argued that, by creating bits of information in dots or dashes to reduce space, the 24 million volumes of interest in the world could be printed on 35 pages:

> All of the information which all of mankind has ever recorded in books can be carried around in a pamphlet in your hand...on just one library card! (Feynman, 1960:24).

This profound concept was enhanced by his next remark which revolutionised technology conceptually:

> Computing machines are very large; they fill rooms. Why can't we make them very small, make them of little wires, little elements---and by little, I mean *littl*e (Feynman, 1960:27).

Feynman argued this radical concept would be achieved through improved electron microscopes. Aware of emerging computer science technology, Feynman comprehended:

> The information cannot go any faster than the speed of light---so, ultimately, when our computers get faster and faster and more and more elaborate, we will have to make them smaller and smaller (Feynman, 1960:28).

This finding is significant in supporting the thesis argument that future medical ETs will be smaller in size. Furthermore, Feynman articulated all of his innovative theories in accordance to the laws of physics:

> As we go down and fiddle around with the atoms down there, we are working with different laws, and we can expect to do different things (Feynman, 1960:24,32).

Feynman's vision for the possibilities of 'nanotechnology' led to another area of great interest to this study:

> A friend of mine (Albert R. Hibbs) suggests a very interesting possibility for relatively small machines. He says that, although it is a very wild idea, it would be interesting in surgery if you could swallow the surgeon (Feynman, 1960:29).

By this, Feynman purported:

> You put the mechanical surgeon inside the blood vessel and it goes into the heart and 'looks' around. (Of course the information has to be fed out.) It finds out which valve is the faulty one and takes a little knife and slices it out. Other small machines might be permanently incorporated in the body to assist some inadequately-functioning organ (Feynman, 1960:29-30).

These ideas of Feynman ignited new scientific fields of research and development (R&D). Fifty years on, medical products are emerging with huge potential forecast for 'nanotechnologies' and 'nanomedicine'. An outline of these anticipations is examined through the works of Freitas and Kurzweil in section 2.3.4-5.

2.3.3 Gordon Moore: Moore's 'Law of Computing Technology'

In 1958, the invention of integrated circuits revolutionised the field of electronic technology (Kaku, 1998:8). Writing on its capabilities in 1965, Moore forecast that the future of integrated electronics would 'bring about a proliferation of electronics, pushing this science into many new areas' (Moore, 1965:para.1). This prediction was based upon Moore's tested scientific theories which, as a distinguished researcher and conceiver of computers, resulted in the much acclaimed publication *The Future of Integrated Electronics* (1964). In this paper, Moore defines the future development rate of computer technology. Now known as *Moore's Law,* this theory predicts future technology progression to be one of continued growth (see Table 2.6). Moore, as well as Feyman, realised the enormous implications of this theory, particularly its role in delivering Feynman's concepts for future medicine.

Moore's Law: is the prediction that the size of each transistor on an integrated circuit chip will be reduced by 50 percent every twenty-four months. The result is the exponentially growing power of integrated circuit-based computation over time.

Table 2.6 Definition of *Moore's Law*.

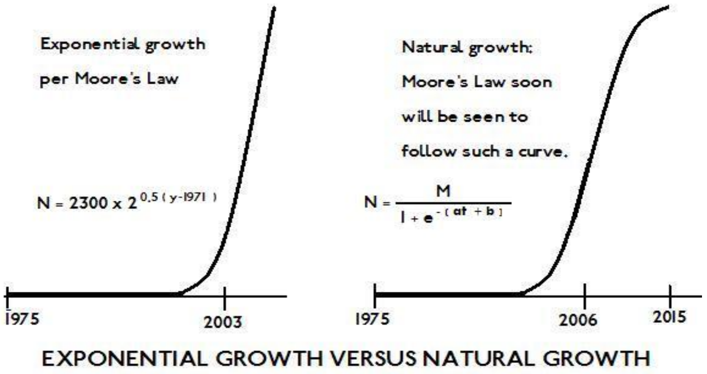


Figure 2.10 Graphed expectations of *Moore's Law* 1975-2015 (thenextwavefutures, 2009).

In general,

> *Moore's Law* doubles the number of components on a chip as well as the speed of each component. Both of these aspects double the power of computing, for an effective quadrupling of the power of computation every twenty-four months (Kurzweil, 1999:306).

Taking this data for technology growth, *Moore's Law* is shown in graph format in Figure 2.10. Commenting years later, Moore states:

> Amazingly we have stayed very closely on the exponentials that were established during the first fifteen year period (Moore, 1995:5).

Broadly, computer microchip technology has followed *Moore's Law* to produce quicker, cheaper and smaller technologies (Moore, 1975:1). This trend continues today with computer processing and speeds doubling bi-annually. As a result, the products of *Moore's Law* have successfully paved the way for social and technological change through the invention of smaller electronics, such as, laptops and mobile phones (Kanellos, 2005). *Moore's Law* is, therefore, vital to the anticipation of future technology growth which predicts the scope for ETs to be smaller technologies.

Moore's Law predicts that current microchip technology has more potential but Moore highlights two possible restrictions.

> The rate of technological progress is going to be controlled from financial realities. We just will not be able to go as fast as we would like because we cannot afford it, in spite of your best technical contributions (Moore, 1995:7).

The second restriction is that *Moore's Law* cannot be sustained indefinitely (Kanellos, 2005). This is based on micro-chip technology's maximum physical capacity which limits the progression of technology. Nevertheless, Moore believes that 'the industry has always blown past barriers in the past' indicating a new revolutionary form of technology is possible (see Figure 2.11). However, the thesis acknowledges great potential still exists for microchip technology. As per *Moore's Law*: huge changes are forecast for future ETs based on microchip's technology growth and the appearance of a major new form of technology by 2025.

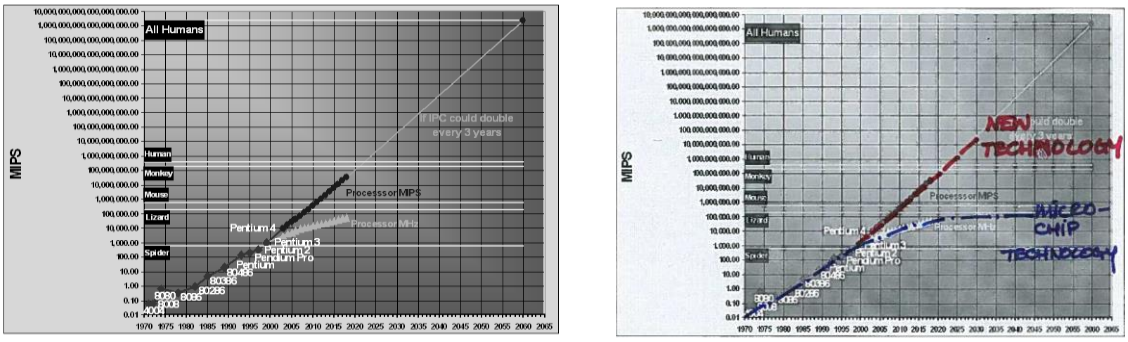


Figure 2.11 Left: The exponential rate of computer technological development as per *Moore's Law* (Fenley, 2004). **Right:** Author's analysis of Figure 2.11 Left.

2.3.4 Ray Kurzweil: *'Law of Accelerating Returns'*

Kurzweil's foresight into future technologies and its implications upon healthcare is long standing. Since the 1970s, Kurzweil has invented significant medical technologies, such as, pioneering speech recognition technology (Pfeiffer, 1998). With respect to ETs, Kurzweil has developed his own scientific model for technology advancement (Kurzweil, 2006:73-84). Scientific progress is defined in his *Law of Accelerating Returns*:

> As order exponentially increases, time exponentially speeds up (that is, the time interval between salient events grows shorter as time passes) (Kurzweil, 1999:30).

From this principle, Kurzweil argues that this century will see dramatic changes in technology on his graphed calculations for computing technology growth (see Figure 2.12). By this, Kurzweil argues that 21st century scientific progress will be '1,000 times greater' than 20th century technology achievements (Kurzweil, 2006:40). In medicine, progression will be driven by revolutions in genetics and robotics (Kurzweil, 2006:40). Sharing Kaku's theories, that developments will be delivered through nanotechnology[7], Kurzweil argues the potential of medical ETs is so great that 'illness as we know it will be eradicated' in the not-too-distant future (Kurzweil, 2006:39).

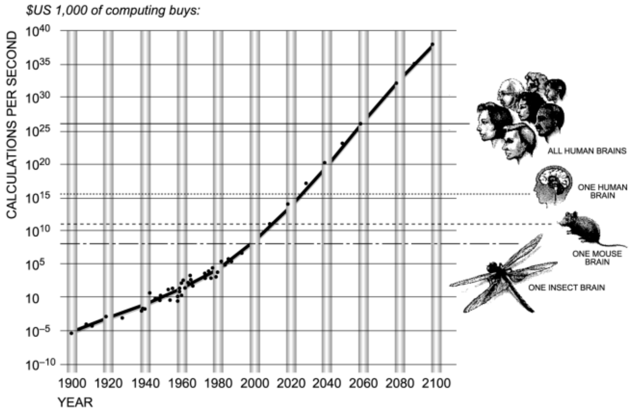


Figure 2.12 Exponential Growth of Computing, 1900-2100 (Kurzweil, 1999:104).

Kurzweil argues that the 2020s will be a strategic future point for technology as new forms of circuitry will revolutionise technology to create computers with human brain

---

[7] See section 7.1 for detailed description of nanotechnology.

capacity (Kurzweil, 1999:102-3; 2006:43). Consequently, digital technologies will become enhanced allowing for the creation of intelligent environments where virtual reality will overlap the real world as technology is embedded in walls, furniture and clothes (Kurzweil, 1999:202-3). Both conceptual examples offer unlimited opportunities for innovative thought for designing future healthcare environments. These ideas present new possibilities to medical planners when visualising future hospital space. In summarising Kurzweil’s concepts, progressive change will surpass 20th century development by ‘1,000 times’ with great strides in medicine emerging as a result of future medical ETs.

2.3.5 Robert A. Freitas, Jr.: ‘Nanomedicine’

As a physicist specialising in molecular nanotechnology, Freitas has written extensively on molecular manufacturing and its impact upon medical science. His work is based on a new field of science called nanomedicine (Freitas Jr., 2005:325). Freitas’ theories are derived from Feynman’s principles of manipulating atomic matter:

> The early genesis of the concept of nanomedicine sprang from the visionary idea that tiny nanorobots and related machines could be designed, manufactured, and introduced into the human body to perform cellular repairs at the molecular level. Nanomedicine today has branched out in hundreds of different directions, each of them embodying the key insight that the ability to structure materials and devices at the molecular scale can bring enormous immediate benefits in the research and practice of medicine (Freitas Jr., 2005:2).

As a result, Freitas predicts:

> In the first half of the 21st century, nanomedicine should eliminate virtually all common diseases of the 20th century (Freitas Jr., 2005:21).

One area to benefit from this technology development will be biotechnology.

> Over the next 5-10 years, biotechnology will make even more remarkable advances in molecular medicine and biobotics-microbiological robots or engineered organisms. In the longer term, perhaps 10-20 years from today,...nanorobots may join the medical armamentarium, finally giving physicians the most potent tools imaginable to conquer human disease, ill-health, and aging (Freitas Jr., 2005:2).

Freitas's insight into future medicine differs immensely from existing medical practice. Notably, these medical predictions are not distant visions, as numerous biotechnology products exist currently. For example, chemotherapy, pacemakers, biochips, insulin pumps, nebulizers, hearing aids and glucose monitoring systems exist as biotechnology products. However, Freitas expects greater volumes of medical products to emerge as a result of ETs (see Appendix B.11).

In addition to consumable medical products, Freitas advocates the development of numerous novel methods, such as, ultrafast DNA sequencing, Fullerene-based pharmaceuticals and biological robots. These all present a future for nanomedicine which Freitas argues is:

> Already close enough to fruition that it is fair to say that their successful developments is almost inevitable, and their subsequent incorporation into valuable medical diagnostics or clinical therapeutics is highly likely and may occur very soon (Freitas Jr., 2005:327).

On this basis, Freitas' anticipations for nanomedicine highlight a new model of care is emerging. From a medical planner's perspective, nanomedicine is radically different from existing medical practice. Based on the future development of smaller technologies, nanomedicine will require new methods to deliver healthcare. This may involve spatial changes which, at present are unknown to hospital designers, and needs to be examined in this study.

2.3.6 Summary

Table 2.7 summarises this section's findings which inform this study's theoretical framework for technology and medical ETs. The identified origins of Toffler's 'third wave of change' coincide with the publication of works by Moore and Feynman. All events pinpoint the arrival of a new age in technology based on theories of quantum physical science and computer growth. These works conceptualised the future of technology which have benefited medical progression and the development of medical technologies. Years of scientific research are emerging with new procedures discovered, such as, the growing and stock piling of biological organs (Kaku, 1998:217-9). This consists of engineered parts being implanted surgically into humans which *The Lancet* records surgeon Anthony Atala as having completed human clinical trials already (Chung, 2006:1215). This clinical trial typifies the potential for medical ETs of which its spatial impact needs to be explored.

Source	Theory	Principles
Moore	*Moore's Law*	Anticipated exponential growth of technology
Feynman	*There's Plenty of Room at the Bottom*	Conceptualised the theory of nanotechnology and future medical scenarios
Kurzweil	*Exponential Growth of Computing*	Medical development through genetics and robotics
Freitas	Nanomedicine	Nanomedicine development through molecular manufacturing

Table 2.7 Summary of section 2.3 Theoretical Framework: Technology and ETs.

2.4 Contextual Framework: Technology and Healthcare

Computer technology has evolved exponentially since the mid-20th century. Included in this progression has been a revolution in the medical field (Moore, 1959; Hillman, 1999:325-8). Similarly, hospital environments since the 1950s have evolved continuously with major functional and spatial problems resulting (Miller & Swensson, 2002:50). Consequently, it became postulated that a fundamental relationship exists between hospital space and technology (Latimer et. al., 2008:80). However, quantitative evidence confirming technology's spatial impact upon hospitals is limited (Hignett et. al., 2007:3). In order to form a contextual framework from which to explore the relationship between future medical technology and hospital space, two aspects of medical technology in healthcare are examined.

2.4.1 Acute Hospitals and Medical Technology

As only one component of any healthcare system, hospitals have been historically the central location for delivering medical care (McKee & Healy, 2002:284). With the recent investment to rebuild NHS estates, hospitals remain physically and theoretically the dominant environment for British social healthcare provision. This status reflects the NHS's original 20th century model of care which, considering current technology capacities and mobilities, is becoming increasingly outdated but signs of change are appearing. For example, remote servicing, home treatments and online help desks represent an evolving healthcare service located outside traditional hospital settings, such as, the NHS Direct telephone helpline (Liddell et. al., 2008:1-2). With telemedicine, telecare and telehealth yet to reach their full potential, similar information technology (IT) solutions will be central to future change and will challenge the role, function and form of NHS acute hospitals. Therefore, as more services are distributed throughout the community, will acute hospitals be required in the future? The thesis believes two reasons support the necessity for future acute NHS hospitals.

First, the origin of acute hospitals was driven financially to concentrate expensive, high-tech medical equipment. This status persists today based on a financial dependency to deliver specialised emergency care in acute hospitals. Expectations are set for this to continue based on an emerging trend since 1980 where clinical information is gained through diagnostic and less invasive techniques through high-tech equipment. While this dependency on sophisticated technology is central to delivering acute services, as more consumers and clinicians demand high quality services, accommodating high-tech equipment in acute hospitals will remain a functional necessity. The second reason regards the recent evolution from new technologies in surgical care. Supporting this trend, national advisor on surgery Lord Alan Darzi, states that the major recent changes in keyhole surgery and laser technology, have contributed to the emergence of complex surgical cases (Darzi, 2007:1-4):

> In recent years we have seen the biggest changes to surgical practice since its inception as a medical and scientific discipline in the nineteenth century (Darzi, 2007:6).

This growth towards less invasive, complex surgical methodologies is delivered operationally with expensive sophisticated medical technology. The most notable recent development is the introduction of robotic equipment which is expected to 'become increasingly widespread in surgery because they can deliver a precision that the human hand cannot match' (Blackman, 2003:15). Both imaging and surgical services are vital components to delivering acute hospitals' main function; emergency care. With a requirement to access specialised staff, tests and scans for quick assessment, as well as intensive care unit (ICU) facilities for post-theatre recovery (24/7), the nature of emergency care forces acute services and medical technologies to remain co-located (Darzi, 2007:5). Therefore, the future role of acute hospitals will remain significant based on medical trends listed in Table 2.8. This finding confirms the necessity for future acute hospitals.

Period of time	Trends for future medical practice
Short term	Minimal-invasive technology (McKee&Healy, 2002:46-7))
Mid term	Endoluminal surgery in the next ten years (Darzi, 2007:7)
Long term	Reduction of interventional surgery. Increased medical therapies and preventative medicine (Kaku, 1998:144-5).

Table 2.8 Current technology trends for future medical practice

Technology can be broadly defined 'as wired and wireless technology' or 'any device, product, service or application with an IT element', as described by The Kings Fund (Liddell et. al., 2008:3). This thesis adopts the USA Office of Technology Assessment's (1976) definition for medical technologies:

> All the drugs, devices and medical and surgical procedures and the organizational and support systems used to provide them (Rosen, 2002:240).

To understand the current scope of medical technologies in NHS hospitals, Table 2.9 lists extracted data from NHS reports (2007). Alternatively, critic David Blackman summarises the current status of NHS technology in *Building Design:*

> Key drivers for change within the healthcare service were social and technological...technology within healthcare is undergoing a phase of accelerated change (Blackman, 2003:15).

Action	Documentation	Technology Data
2000	*The NHS Plan 2000* (Wanless et. al., 2007:105)	250 scanners and latest IT system to be delivered by 2010.
2006	*Wanless Report 2006* (Wanless et. al., 2007:129)	'By April 2006...about 71 per cent of MRI scanners, 77 per cent of CT scanners and 75 per cent of linear accelerators were purchased since January 2000'
2007	DOH Report, 2007 (DOH, 2007:3,4)	'In 2006 NHS Trusts and PCTs invested £733 million in capitalised equipment' . Since 2000 - 156 New magnetic resonance imaging (MRIs) (82%), 157 new Linear Accelerators (82%), 231 computer tomography (CT) scanners (76%). 90 new cardiac catheterisation Laboratories (40% new) On completion, the programme will have 27 new cardiac theatres and 620 extra beds.

Table 2.9 Existing NHS medical technologies currently in use and expenditure (2007).

This current state is not without problems. For example, in comparison to the adoption of new technologies by the banking and travel sectors, the Healthcare Industries Task Force 2004 described the NHS 'as a late and slow adopter of medical technology' (Wanless et. al., 2007:59; Liddell et. al., 2008:2). This concern was addressed similarly by the then government adviser, Sir Derek Wanless:

> In 2005, the Health Committee's report *The use of medical technologies within the NHS* (2005) noted the department's concern about their continued slow take-up (Wanless et. al., 2007:59).

This slowness has left NHS technology use way behind other countries. This status is a direct outcome of UK expenditure on medical technology being 0.36% of gross domestic product (GDP) rather than the European average of 0.55% (Morgan-Hughes et. al., 2005:731-2; Mayor, 2005:861). Consequently, 'in many acute trusts the budgets for new medical equipment have been reduced, regardless of the merits of individual business cases' (Liddell et. al., 2008:24). This concern is supported by Wanless' argument:

> Subsequently, no target or implementation process was introduced to promote technical innovation across the NHS as a whole...no large scale vision of the potential of new technology has emerged (Wanless et. al., 2007:59).

This lack of strategic planning for medical technologies within the NHS is unsatisfactory.

2.4.2 Current ETs and Healthcare

Insight into future medical technologies is crucial for the medical planning of hospitals. However, designers have only a two-to-three year product knowledge for future medical equipment. With expectations believed to be so radical that 'human existence will undergo a quantum leap in evolution', it is critical for medical planners to understand the implications of medical ETs with regards to future medical practice and technologies themselves (Kurzweil, 2006:39). Generated from *Moore's Law*, technology's exponential growth rate is set to continue through the emergence of novel medical ETs (Kurzweil, 1999:102-5). For example, concepts such as 'swallowing the surgeon', 'Lab-on-a-chip' and medical nanorobots all visualise a very different future for healthcare practice (see Chapter 7). How these will affect hospital space is central to the thesis argument and is explored in detail in Part III's discussion of medical ETs impact on future hospital space.

2.4.3 Summary

Healthcare heavily relies upon technology as a tool to save lives. In 2012, not only is technology embedded in the fabric of hospital buildings, it has become key to all processes, management and delivery within a hospital's organisation (Liddell et. al., 2008:1-3). Overwhelming evidence envisions a future of radical change whereby medical technologies are anticipated to be recipients of this technological revolution. Based on the scientific evidence of Kurzweil, Kaku and Freitas, it was shown that predictions for medical ETs are formed of ubiquitous, robotic and biomolecular technologies. While discrepancies arise throughout literature concerning technological times of arrival, all theoretical works unanimously conclude that radical change in healthcare is fast approaching. By 2025, nanomedicine is predicted to be a new and developing model of care. However, information regarding its delivery and design requirements appears to be non-existent. For example, research into medical technologies and their spatial design implications was compiled from the National Institute of Health Research's (NIHR) list of conducted research (NIHR, 2011). Sixty-one projects are recorded with only twelve projects focusing on design (19.6%). One project explored technology (1.6%) but this paper, published in 2004, does not consider ETs. Additionally, the NHS's position on medial ETs is considered behind the rest of the world which is not surprising considering 'nanotechnology does not rate as highly as microtechnology in the Department of Trade and Industry frontiers' (Gibson, 2004: Col, 443WH). However, this situation is alterable, and considering ETs unpredictability, scope for major developments are still predicted for 2020 (see Table 2.10).

Available now	1–5 years away	5–15 years away
Sunscreens, semi-conductor lasers for telecommunications. Harder, stronger, lighter materials.	"Lab–on–a–chip" technologies, smart nano–coatings for packaging, minute tracking devices.	Targeted drug delivery & virus detection. Better medical implants and artificially created organs. Molecular methods for disease diagnosis. Non–invasive molecular imaging in medicine.

Table 2.10 Taylor Report:Table 1: Present and future commercial applications of nanotechnology. *Source: Ev 35 (edited).* (House of Commons Science and Technology Committee (HCSTC), 2004:8).

2.5 Chapter conclusion

This chapter provides a theoretical and contextual framework for this thesis's empirical research on technology's relationship with hospital space. A summary of findings and a final conclusion complete Chapter 2.

Typologies were chosen on the merit of their architectural theories rather than the historical types that dominated 20th century hospital design. Medical planning principles of separation, indeterminacy and standardisation were established as critical elements for creating successful and flexible NHS hospitals. Each hospital typology by Aalto, Weeks and Le Corbusier gives insight into an array of medical planning principles that delivered adaptable solutions during a time of revolutionary hospital spatial change.

In 2012, society is embarking on a ‘third wave of change’ which anticipates ETs to play a pivotal role in revolutionising medicine. Based on the scientific data from works by Moore and Kurzweil, it was shown that future technological progression is anticipated to surpass all previous achievements. The impact of these extrapolations is the basis of Feynman, Kaku and Freitas’s medical scenarios in which ubiquitous digital technology, robotics and biomolecular technology are expected to revolutionise healthcare practices. However, limited technical information exists regarding the delivery of this new medical model even though expectations are for the ‘accelerating impact of new technologies’ to heavily affect healthcare delivery (Future Healthcare Network (FHN), 2004:5). Regarding its architectural implications, if nanotechnology is to transform how the health industry works, the thesis seeks to understand the spatial implications that result from medical technology changes.

The concerns surrounding current hospital design methods stifle innovation and cause concern for PFI NHS hospitals. It is argued that the PFI process:

> Needs an overhaul to give trusts sufficient flexibility to build future-proof hospitals that can adapt to healthcare changes in the next decade and beyond (FHN, 2004:6).

Nevertheless, excluding PFI restrictiveness, the current outdated hospital design model is responsible equally for running a high-risk possibility of premature invalidity. This concern is based upon the outcome of late-20th century hospital buildings which struggled to adapt to evolving sophisticated technologies (see Chapters 4-5). Combined, these factors curtail the development of 21st century NHS hospital design which delivers beneficial outcomes on many levels when designed flexibly and appropriately:

> The business case for good design becomes clear when...staffing costs represent about 80 percent of the running costs of a typical hospital....a small change in staffing/running costs can make a very large difference to total running costs of a healthcare building over its lifetime (FHN, 2004:6).

Therefore, considering the NHS’s £25 billion estate, an ability to reduce costs through strategic design is essential as an architectural principle for designing future NHS hospitals (DOH, 2007:2). While the realities of medical ETs are not yet fully understood, it remains vital that all medical planning possibilities for NHS hospitals are explored to ‘carry the estate into the next millennium’ (Maxwell, 1996:11). Equally if nanotechnology has the ability to create smaller electronics, why are we over-sizing current hospital spaces and building excess area into NHS hospitals at taxpayers’ expense? The necessity to answer this question is a core purpose of this particular study. The next chapter’s discussion upon the thesis’ methodological approaches explains how this is achieved.

Chapter 3: Methodological approaches

"A journey of a thousand miles must begin with a single step"

Lao Tzu

3.0 Introduction

This chapter presents the research design and methodology employed in the thesis. This is a single future prospective methodology and mixed methods approach. As outlined in Chapter 1, the thesis seeks to determine the relationship between hospital space and technology to critically assess the implications of medical ETs on future urban acute hospitals. Informed by the theoretical and contextual frameworks presented in Chapter 2, this chapter describes the methodology and methods incorporated to achieve the four objectives set out in Chapter 1. The chapter begins with a background description as to how the thesis focus was developed which leads to a set of identified hospital design influences. From this, a strategy for the thesis was formed in a structured and logical manner based on the four thesis objectives. Subsequently, details of the study's methodology and methods are described which is followed by a discussion of the approach applied for data collection and analysis. In an attempt to envisage the unpredictable, a further scenario approach is adopted to assist medical planners with future-proofing medical planning possibilities for future urban acute hospitals. This is followed by an outline of thesis limitations. The chapter concludes with an analysis and a set of variables identified for the core research.

3.1 Development and justification of thesis focus

The extent of medical planning is varied and broad, ranging from the masterplanning of vast green-field healthcare campuses to the intricate detailing of a single patient-bedroom design. Due to its extensive nature, the author wished to undertake a study of only one aspect of medical planning. Hence, the thesis concentrates explicitly on the seemingly less studied D&T hospital component (see section 3.5). The decision for this focused study is driven by two contributing basic factors. The first reason is to advance the gap in knowledge to which this particular area of medical planning appears limited.

For example, patient-care design is researched extensively, such as, the spatial and medical implications associated with decentralised nursing stations. There is a need for the impact of medical technology on hospital space to be explored, as no specific analytical data seems to exist. The second factor is more pragmatic and is based upon the author's experience as a medical planner. As an eyewitness, one of many difficulties in designing acute hospitals is the on-going changing spatial demands required to accommodate medical technologies. This topic is an area of medical panning which the author wishes to explore.

3.1.1 Identifying research variables

The thesis focus is refined explicitly to analyse future hospital space. Four independent and one dependent variable were identified for research from five established parameters:

(i) Hospital type: Numerous hospital types exist based upon age, gender or acuteness. In response, hospital typologies differ immensely between varied specialities. Based on this criterion, only one typology type is considered in the thesis. Three reasons account for the decision to explore NHS acute hospitals:

1. Acute hospitals reflect a large sector of the NHS healthcare system
2. The latest NHS hospital rebuilding programme has produced a multitude of NHS acute hospitals worthy of exploration as 'state-of-the-art' hospitals
3. Recent healthcare policies have centralised expensive medical equipment in NHS acute hospitals (Tomlinson Report, 1992). Simultaneously, most NHS acute hospitals have experienced on-going spatial problems and, therefore, an investigation of these parallel events is considered necessary.

(ii) Sample location: The medical planning of acute hospitals differs considerably between rural and urban locations based on site topography and available ground surface area. Urban acute hospitals face on-going design problems as a result of expansion needs and maximum site constraints unlike rural sites where future hospital expansion issues are not as complex or challenging (Diamond, 2006:26). Taking geographical differences into account, only one variable can be covered within the thesis scope. An urban location was chosen to contribute the gap in understanding the spatial design problems relating to the study's hospital type.

(iii) Sample city: As urban populations vary widely, the thesis wished to refine the focus of the sample. One city type was chosen with a population of approximately 14 million people and an expected growth of 20% by 2050. This classified ten world cities into a sample: Cairo, Manila, London, Buenos Aires, Moscow (van Susteren & van Arjen, 2005:14). A study upon each of these city's hospitals would exceed this study's boundary. Therefore, London became the representative sample city, as it possesses numerous relevant hospital case studies worthy of investigation.

(iv) Medical planning flow type: The complexity of movement around acute hospitals creates numerous types of flows. These include outpatient visitor or non-clinical staff flows. The thesis chose to focus upon the main flow associated with acute-care focused departments (see section 3.5). This is the UAT patient flow, which centres upon the stabilisation, diagnosis and treatment of UAT admissions.

(v) Technological specification: The logical choice for the technological variable is medical ETs based on the thesis focus to explore future hospital space. As previously defined, medical technologies are:

> All the drugs, devices and medical and surgical procedures and the organizational and support systems used to provide them (Rosen, 2002:240).

Seven medical ETs emerged from literature but four were omitted for reasons described in Appendix C.1. The remaining three - biotechnology, robotics and cybernetics - are chosen based on anticipations that these medical ETs would be medically operational in 2025. Figure 3.1 depicts the hierarchy identified for thesis medical technologies.

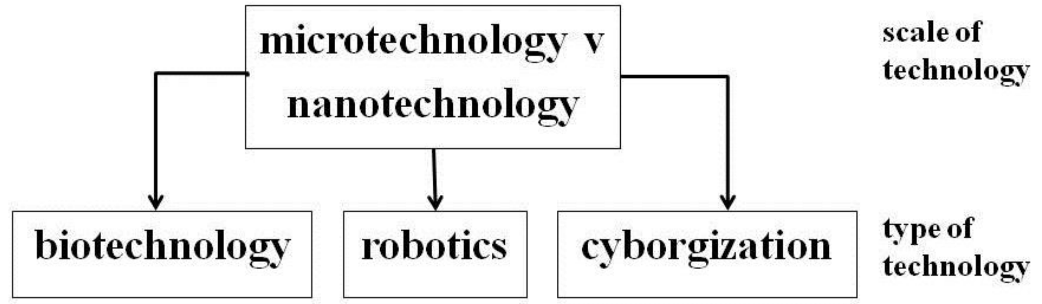


Figure 3.1 Thesis hierarchy diagram: Medical ET relationships.

To summarise this section's decisions, Table 3.1 re-states the chosen variables.

Research Parameter	Thesis focus	Variable Type
Hospital type	Acute hospital	Independent variable
Sample location	Urban context	
Sample city	London city	
Medical planning flow type	UAT patient flow	
Technological specification	ETs	Dependent variable

Table 3.1 Table of research parameters, thesis focus and variable types.

3.1.2 Concept mapping: Defining hospital design influences

The process of designing hospitals is not solely based on an architectural brief (see Appendix C.2-3). Numerous factors infiltrate through to the creation of hospital spaces, adding further complexities to the medical planning of hospitals (Rosenfield&Rosenfield, 1969:42-3). Such as, current UK healthcare policy dictates a model of care that reduces hospital bed numbers while, what McKee and Healy refer to as, Soviet-model healthcare systems maintain a high bed number policy for purposes of civic pride (McKee&Healy, 2002:30). Each healthcare policy drives a different typological response, supporting the argument that other factors influence the design of acute hospitals. This principle directs the next identification process which centres upon determining all dominant hospital design factors.

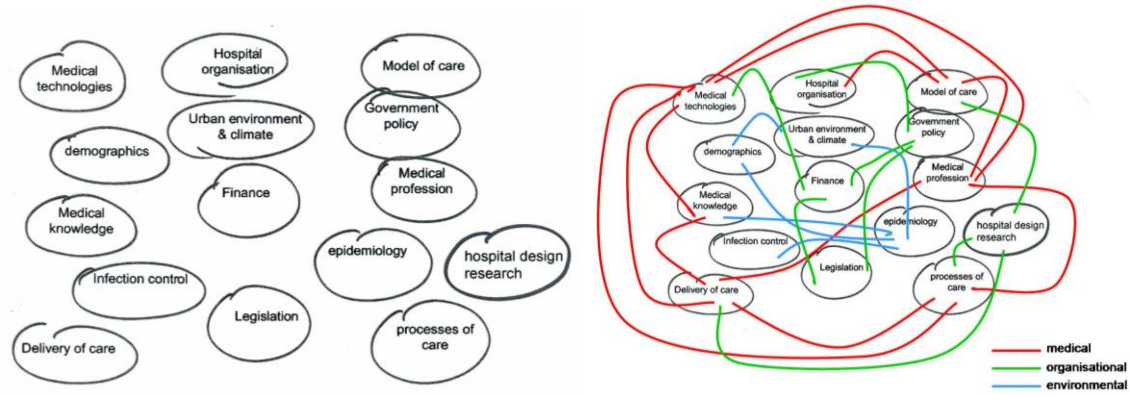
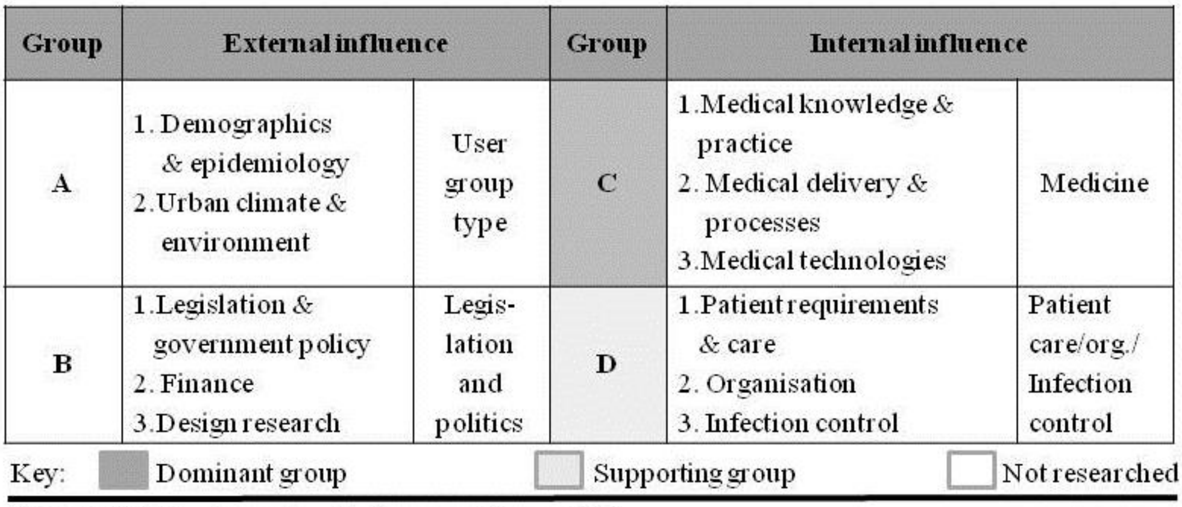


Figure 3.2 Left: Author's initial concept map sketch. **Right:** Author's updated concept map sketch: Linked factors.



Group	External influence		Group	Internal influence	
A	1. Demographics & epidemiology 2. Urban climate & environment	User group type	C	1. Medical knowledge & practice 2. Medical delivery & processes 3. Medical technologies	Medicine
B	1. Legislation & government policy 2. Finance 3. Design research	Legis-lation and politics	D	1. Patient requirements & care 2. Organisation 3. Infection control	Patient care/org./ Infection control

Key: ▨ Dominant group ░ Supporting group ☐ Not researched

Table 3.2 Table of organised influences: Groups A-D.

Hospital design influences were identified through the incorporation of Joseph Novak's concept mapping technique:

> Concept mapping is a technique for externalizing concepts and propositions (Novak & Godwin, 1984:17).

Reflecting hospital design processes, this procedure informs the area of medical planning theoretically. Through step-by-step processes that identify, test and organise all relationships visually, all key hospital design influences were nominated and mapped initially (see Figure 3.2). As Novak argues, initial concept maps are almost certain to be flawed and will need to be redrawn to identify important hierarchical relationships between concepts (Novak, 1984:35-6). The incentive to redo concept maps is to increase the meaningfulness of compositions. Hence, this study's concept mapping procedure was repeated numerous times to detect similarities and connectivities (see Appendix C.4-6). The outcome established many relationships which were categorised into external or internal design influences. Charted findings clarify this arrangement to form four group types (see Appendix C.7-9). Group C's set of hospital design drivers was deemed the most significant regarding technology's impact on hospital interiors space (see Table 3.2). Each of Group C's medical influences is examined in Chapters 4 and 5's empirical exploration.

From established variables and hospital design influences, research into future hospital space and medical technology can be explored. A single quantitative methodology and a mixed-method approach are employed to respond to research objectives described next.

3.2 Research aims and objectives

Four objectives were developed to contribute to proving medical ET's influence upon future hospital space. This section describes each objective with considerations from two perspectives: (i) the objective's significance within the larger context; (ii) its role in proving the main thesis argument.

3.2.1 Confirming the assumed relationship between hospital space and technology

The necessity for flexibility is underpinned by the principle that hospital design influences are evolving indeterminately. Technology is one of these design factors, which is presumed critical in driving hospital space. Empirical studies to confirm this assumption however appear non-existent. Therefore, this study's exploration will confirm technology's relationship with hospital space, thus, supporting the main thesis' argument that medical ETs and future hospital space will be linked. Using section 3.1.2's identified hospital design influences, a historical review of medical planning provides; an understanding of hospital design, its revolutions and dominant influences that have impacted previously on hospital space. This is followed by an exploration of medical technology development and its growth within British hospitals. Thereafter, a critique of all findings determines the existence of a relationship between hospital space and medical technology.

3.2.2 Investigating technology's influence as a driver of hospital medical planning

The aim of the second objective is to quantify and identify technology's role as driving hospital medical planning. At present, studies that explore this relationship seem non-existent within a UK context particularly for PFI NHS hospitals (McKee & Healy, 2002:241). While spatial requirements for medical technologies are demonstrated easily through HBN SOAs, technology's role in configuring hospital space remains unexamined quantitatively. Therefore, empirical evidence is necessary for determining technology's status as a design influence for the benefit of producing sustainable future NHS hospital space. To achieve this objective requires the examination of technological events and revolutions leading up to present day hospital design. Through Part II's historical literature and case study explorations, the aim is to investigate technology as a design driver by critiquing the spatial changes within hospital typologies that resulted from new and upgraded medical equipment. Findings will show technology's role in evolving British hospital space, which thereafter will be used as evidence to examine medical ET's influence on future NHS hospital space.

3.2.3 Investigating the implications of medical ETs for future UAT treatments and associated hospital spaces

No empirical work exists to analyse future spatial implications of medical ETs. Hence, an exploration of predicted medical technologies needs investigating to establish medical ET's impact on future UAT hospital space. From Chapter 2's technology frameworks emerge three significant medical ETs. These include biotechnology, robotics and, a combination of both, cyborgization. Each medical technology is a dependent variable for healthcare progression covered within the study. To achieve this third objective, identified medical ETs are discussed from an UAT medical planning perspective. By establishing the changes between current and future healthcare practices, spatial implications associated with this patient flow can be identified. A scenario approach is applied to visualise how each medical ET impacts on hospital space. This directs the study towards visualising future medical planning solutions from which to assess the final thesis objective.

3.2.4 Assess the necessity for flexible hospital design solutions

The fourth objective is aimed at confirming the necessity of flexible hospital design solutions, particularly with reference to the durability of 'state-of-the-art' PFI NHS hospitals. As little in the way of empirical work has studied technology's role in creating flexible hospitals, more research is needed to support the reasoning for incorporating flexible medical planning solutions. Hence, this study provides a source of empirical knowledge from which future studies can be founded. This objective is achieved by drawing on data that emerged throughout the study, specifically from findings revealed in achieving objectives two and three. New knowledge will allow for PFI NHS hospitals to be assessed, which will inform the need for flexible design solutions in acute hospitals. In turn, the thesis concludes with guidance offered in the form of recommendations for future medical planning strategies and potential further research.

3.3 Research framework

The research framework of this study consists of two areas: methodology and method. Methodology is the philosophical stance that informs the research while method is the techniques employed to collect and analyse data. The thesis consists of the following methodology and method approaches.

(i) Thesis methodology

The context of the current study aims to explore the impact of medical technology on hospital space. This involves researching only one aspect of hospital medical planning. Hence, a single methodology research design was deemed as appropriate to address the research question identified in section 1.2.

To create a vision for future hospital space involves an understanding of current hospital design drivers, anticipated trends and forces that are driving hospital space to change. Two underlying forces of complexity and on-going change are examined in this study through medical ETs explicitly. To understand how medical ETs will affect future hospital space calls for a methodology that demands ‘outside-the-box’ thinking to assist medical planners with designing flexible and sustainable NHS hospitals.

Traditionally, to predict the future is impossible and therefore unadvisable. Instead, a more reliable solution is to estimate major future trends and effects (Orrell, 2007:269). Adopting this approach to this study requires a particular future-oriented methodology. The thesis draws from the generic field of ‘futures studies’ and specifically, Elzbieta

Krawczyk and John Ratcliffe's 'prospective process' as research in the field of medical planning is limited (Krawczyk & Ratcliffe, 2005:3-4). This methodology originates from the conceptual frameworks of business strategy applications. Its principles reflect medical planning practice insofar that long-term vision and strategies are required for sustaining functionality and flexibility. The importance of strategic planning is to create a vision for a desirable future state (Gower, 2011:20).

> Fundamentally, strategy is a series of measures adopted to achieve a stated aim (Gower, 2011:20,13).

The concept of strategic planning emerged as a methodology in the mid-1960s (Ansoff, 1965) to allow for turbulence within company environments and to adapt company goals accordingly (Ratcliffe & Sirr, 2003:4). One notable model is Prof. Henry Mintzberg's *Five P's for Strategy* (see Table 3.3). Theoretically, the main principle consists of an ability to predict and to react to unplanned events.

Mintzberg's *5P's*	**Strategy Description**	**Relevancy to thesis**
Plan	looking ahead, advanced planning for future actions	relevant
Pattern	looking at past behaviour, realising consistency in actions	
Perspective	management related about vision of company	
Position	market related in finding niche/	irrelevant
Ploy	market related to competing opponents	

Table 3.3 Tabled of Mintzberg's: *Five P's for Strategy* (Mintzberg, 1987:11-24).

By the 1990s, a new 'strategic prospective' model was developed by Michel Godet at the French School. His *la prospective* distinguishes between the theoretical approaches to prospective and planning (Goget, 1991):

> The prospective wants to open the scope to look further into the future...to improve the chances of detecting all the conceivable variables and project them as far as possible (Ratcliffe & Sirr, 2003:5).

In contrast, planning focuses on placing concrete objectives within the near future to determine an accomplished future perspective. As Godet suggests, planning is too restrictive for creating long-term strategies. On this basis, a planning methodology for the thesis was identified as inappropriate for exploring future hospital space. Instead, the thesis draws from a more recent *la prospective* model, which was adapted by Krawczyk and Ratcliffe. In their *Imagine ahead – plan backwards: Prospective methodology in urban and regional planning*, a 'Prospective' model for urban planning use was developed (Krawczyk & Ratcliffe, 2005). This model consists of five main research phases, of which, one is a scenario method for visualising future possibilities (see Appendix C.10).

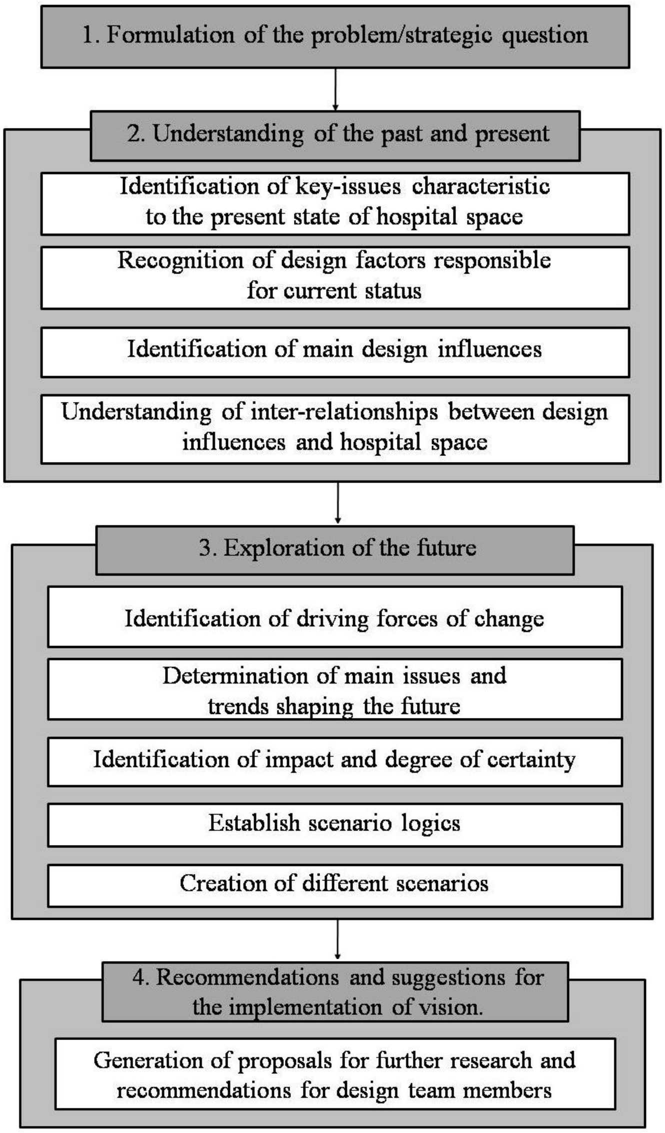


Figure 3.3 Thesis methodology: Self-created single future 'prospective' methodology.

The principles of Krawczyk and Ratcliffe's 'Prospective' model were considered an appropriate approach for this particular study. This decision is based on this study's empirical research, which does not measure patient experience, safety or medical errors. Instead, the nature of measuring and visualising hospital space (units/square meters (sqm)) dictates the necessity of a particular future-orientated methodology. Hence, the thesis forms its own methodology as a derivative of Krawczyk and Radcliffe's 'Prospective' model. The study's unique self-created methodology is formulated in Figure 3.3 and seeks to contribute to advancing the development of medical planning knowledge. The methodology is aimed at achieving visions for future urban acute hospital space by offering a range of possible future medical planning scenarios.

(ii) Thesis methods

The objectives set out in Chapter 1 are achieved by employing a mixed-method approach at different stages of the study. A single quantitative approach for data collection is used first and then followed by two methods for data analysis.

The first method employed determines an understanding of past and present events, specifically, key spatial issues and design influences of hospital medical planning. The method used is a historical review of literature, photographs and drawings, which is followed by a quantitative approach to support findings arising from the first method. The second process is delivered through a single case study method, which focuses on the measurement of high-tech space in urban acute hospitals (see Table 3.4). This is implemented through the area measurement of post-1840s London hospital plans. Data arising from the case studies allows for technology's link with hospital space to be confirmed while quantifying technology's impact as a driver of hospital medical planning. The third method is the creation of scenarios, which are based upon identified driving medical planning forces, data analysis from the case studies as well as projections from ET literature. By creating scenarios a visualisation for future urban acute hospitals is formed. Findings inform the assessment of PFI NHS hospitals' durability.

3.4 Research Design

The research objectives pursed in this thesis are concerned explicitly with technology's impact on the configuration of NHS hospital space. Hence, the selected research design is structured to collect and analyse data that reflects this concern. Three research phases are employed to best meet the four thesis objectives:

Part I: Thesis frameworks and structure

Part II: Exploration of technology's relationship with hospital space

Part III: Exploration of medical ET implications and visions for future hospital space.

This study provides a valuable source of empirical knowledge that will enable medical planners to understand the impact of medical ETs on future hospital space. Additionally, the study's self-created 'prospective' methodology and mixed-methods approach will contribute to future medical planning research, as knowledge is limited in this particular medical planning area.

3.5 Quantitative framework: Case study sample criteria

In section 3.1.1, the sample for case study research was identified as: NHS acute hospitals in London's Zone 1 area. Further to this, hospital building components and departmental criteria for this study needed to be determined. The first criterion is to categorise hospital departments into one of two hospital building components: high-tech or low-tech areas. Characteristics for high-tech and low-tech space are listed in Table 3.4. The second criterion that needed defining was the sample's departmental list. Departments were assigned to their associated hospital building component as per current medical planning practice (see Appendix C.11-2). Nineteen departments were listed with twelve categorised as high-tech. Not all are associated with the UAT patient journey, such as, Mortuary. Consequently, only five high-tech departments matched the thesis criteria (see Table 3.5). These areas are the focus of this study's empirical research.

Building component	% of Technology	Functionality	Description of space
HIGH-TECH	High concentration with high-spec criteria	Diagnostics, Treatment & support	Hard space (space not designated for future expansion)
LOW-TECH	Low concentration with low-spec criteria	Care, consultation & support	Soft space (space designated for future flexibility and expansion)

Table 3.4 Characteristics of hospital building components: High and low tech space.

HIGH-TECH BUILDING COMPONENT: DEPARTMENTAL AREAS	
Department	**Functionality**
A&E	Resuscitation, trauma, observation and assessment
Imaging	Diagnostics through the use of high-spec technology: Multi-slice CT scanner, positive emission tomography (PET)/CT scanner, Fluoroscopy, X-rays, MRI.
Theatres	Specialist and interventional theatres, anaesthetic rooms, etc.
Pharmacy	High-tech laboratory areas with higher mechanical and electrical (M&E) requirements
Pathology	High-tech laboratory areas with higher M&E requirements

Table 3.5 High-tech building component: List of departments.

The aim of the case study is to quantify the nature of British hospital space. Both historical and current London hospitals need evaluating to understand past and present inter-relationships between medical technologies and hospital space. The case studies chosen allow for variety in hospital characteristics and spatial change to be measured to quantify technology's role in forming current hospital medical planning. Time restrictions and limited resources directed the case study research to choose four hospitals where each represents a main geographical extent of central London. Additionally, four fixed variables were introduced to refine the case study's focus:

period of existence; nature of organisation; hospital type; location. This resulted in a specific case study sample; an NHS teaching facility based in central London with an A&E and associated UAT departments. A timeframe of 1840-2012 emerged as significant from Chapter 4 and 5's findings. This specific fixed period records the introduction and development of medical technology in hospitals. Over periods of approximately fifty years, each set of plans is measured quantitatively for 1840-2012. Two pertinent questions are asked of each hospital case study:

(i) Is technology growth identified quantitatively?

(ii) What spatial trends and relationships are reflected between high and low-tech areas?

Quantitative data lends itself to determining technology's position as a dominant driver, thus, proving medical technology's link with acute hospital space.

3.6 Data collection

Data were collected from four main sources, which involved various timescales and procedures (see Appendix C.13-20). For example, the Royal London Hospital (RLH) and St. Thomas' hospital required archival research to locate pre-1900 plans. Twelve sets of hospital plans were located ranging from 1832-2012. Case study data collection is summarised next.

The first source was the RLH of which six set of plans were located (see Appendix F.1-11). Two processes were required for collection at the RLH. All pre-1950 literature, plans and photographic evidence required research at the Trust's archive department. Post-1950 plans, held within Skanska's on-site construction offices[1], were sourced at separate meetings. A full set of metric plans was available in electronic format

---

[1] Skanska is a big multi-national British building contractor. Offices visited were both located at the RLH, Whitechapel Road, London.

(AutoCad) for the new 2012 hospital. However, only some electronic plans (AutoCAD) were available prior to 2000, as the majority of previous plans exist as scanned hand-drawings. The second source was St. Thomas' where four sets of hospital plans were located (see Appendix F.20-2). These were researched over a number of daily visits at the Trust's office at Guy's Hospital. This process included research into literature, photographic and spreadsheet SOA material which, combined, created an accurate account of the hospital's historical and current typologies. The third source for the Chelsea and Westminster hospital was Sheppard Robson architects. This case study exists as a single set of drawings due to its recent relocation. No changes have occurred to the hospital's typology since its opening in 1992. Electronic plans in AutoCad format were available as a record of current departmental layouts. The fourth source for University College London Hospital (UCLH) was the Trust and the hospital's architect. Only one set of fragmented electronic plans was available but a complete SOA spreadsheet was created. SOA information was received from two sources: the Trust and Llewellyn-Davies (LD) architects (see Appendix F.43).

3.7 Data analysis: Case studies

One sample, rather than multiples, is employed in this research as variation for spatial analysis is sought between urban typologies instead. As a result, the method employed for case study analysis is a single quantitative approach. This method allows for a range of, but cohesive, set of spatial findings. Based on measured data, numerous analytical questions explore and define the existence of relationships and trends. The aim of this quantitative method is to support previous findings and conclusions by demonstrating that the study's research is rigorous through comparative quantitative analysis.

Industry standards exist for the measurement of hospital space but no documentation seems to exist for the specific analyses of hospital high-tech areas. The author, therefore, established the following protocols for measuring this study's case study plans. Five standard terminologies, typically used by British medical planners, were adopted for measurement (fully defined in Appendix C.21):

1. Gross Departmental Area (GDA) = high/low tech areas
2. Gross Communications Area (GCA)
3. Gross Plant Area (GPA)
4. Gross Facility Management Area (GFMA)
5. Gross Building Area (GBA): GBA = GDA + GCA + GPA + GFMA.

All case study plans were measured and recorded in metric form per sqm for consistency even though plans prior the 1960s were drawn imperially. Areas are measured per department with results grouped for analysis under one of four headings: 1. High-tech, 2. Low-tech (Wards), 3. Plant/Comms., and 4. Facility Management (FM) (where applicable).

Originally, the measurement of plans was to be calculated electronically. However, data limitations and inconsistent formats directed analyses to be conducted by hand calculations and SOAs. All areas were calculated as per the established protocol with all results recorded in a single standard format of measurement. Quantitative data is examined through research objectives and questions that compare the changes in hospital space against Chapter 5's identified rates of technology development. Findings and results are detailed in Chapter 6 where a conclusion was determined: medical technology is a dominant driver of NHS hospital space.

3.8 Data Analysis: Scenario creation

The final phase of this study's 'prospective' methodology is visualising the future. Explorations are based on analysed findings and are conducted through a scenario creation method.

> The prime purpose of scenarios is to enable decision-makers to explore alternative futures so as to clarify present actions and subsequent consequences (Ratcliffe, 2000:3).

Typical uses for the scenario method include the future planning for the European Commission, the USA defence industry and the UK's NHS (Ringland, 1998). The aim of this study's scenario creation is to understand the impact of medical ETs on future hospital space.

Thesis self-created prospective 'scenario' formula
1. Identification of the driving forces of change 2. Detection of the main issues and trends shaping the future 3. Establishment of scenario logics 4. Creation of different scenarios

Table 3.6 Thesis scenario formula.

As per Krawczyk and Ratcliffe's 'Prospective' methodology, scenario creation consists of three methods: scenario thinking; scenario logic; scenario building (Ratcliffe & Sirr, 2003:3-9). The third method of scenario building is excluded here, as this study is not concerned with policy formation. This decision is driven by the principle that scenario building is essentially a team exercise that explores distinct and plausible futures that simply project the past forwards (Shoemaker, 1998). This is not the intent of this research, which seeks to conceive all possible futures for medical ETs at this early stage of development. Therefore, this study's scenario creation is focused on instigating a variety of future medical planning ideas. Consequently, this study created a unique scenario method that is underpinned by Krawczyk & Ratcliffe's proposed scenario technique (Krawczyk & Ratcliffe, 2005:9). Listed in Table 3.6, a four-step formula is employed to achieve Chapter 8's scenario creations. The first two steps are formed from the study's determined major trends and influences. Scenario logics are introduced to evaluate areas of future medical planning uncertainties. Four parameters for scenario logics are outlined next.

(i) Scenario Logics

Scenario logics are defined as:

> The underlying principles around which the different scenarios are structured. They focus on the pivotal uncertainties...and present alternative theories of the way the world might work (Ratcliffe, 2004:28-9).

The purpose of scenario logics is to establish a logical structure and rationale for scenarios by trying to make sense of uncertain drivers of change. These include superforces and shocks, which have not been examined within this study. This exploration demands a thesis by itself but awareness of external influences has been noted throughout. One force is central to this study: technology's current status within NHS hospitals. To upgrade NHS technology's status to an internationally recognised high standard, will incur spatial changes regardless of ETs. Hence, the organisation of NHS technology is considered this study's 'superforce'. This factor underpins the four scenario logics laid out in Table 3.7. Scenario logic No.4 is considered uninformative as no change is expected to occur to hospital space. This directs the empirical exploration to create three plausible scenarios from scenario logic groups 1-3.

Scenario Logic No.	Scenario Group type	Scenario Logic No.	Scenario Group Type
1	High technology growth where NHS implements medical ETs in hospital space	**3**	High technology growth where NHS cannot implement medical ETs in hospital space
2	Slow technology growth where NHS implements medical ETs in hospital in space	**4**	Slow technology growth and no implementation of technology in NHS space

Table 3.7 Scenario Logics: Four group types.

Each scenario is self-contained, and having its own scenario logic, depicts alternative spatial visions for medical ETs in London acute hospitals. Furthermore, each scenario is structured upon a general UAT patient flow. This flow is generated by patients' first entrance to hospital via A&E. Once admitted, patients flow differently between the five high-tech departments established in section 3.5. A flow chart showing UAT patient movement for scenarios replicates current medical practice (see Figure 3.4). Typical departmental rooms discussed within scenarios are drawn from relative HBN guidance listed in Appendix C.22.

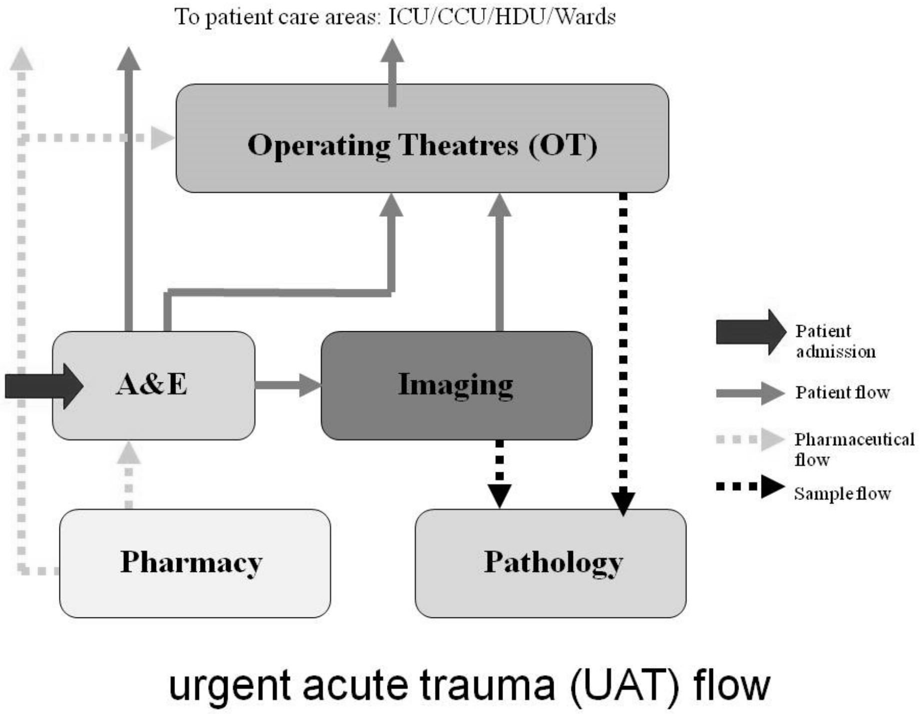


Figure 3.4 Scenario creation: Existing departmental flows for UAT patients.

3.9 Limitations

The current study acknowledges the thesis is subject to limitations. Five areas of recurring data collection and analysis limitations were experienced.

The first restriction relates to the data collection of hospital drawings. As a student, great difficulty was experienced in sourcing NHS hospital plans. The main hindrance for acquiring plans included risk of confidentiality, their non-existence, a lack of filing systems, an inability to convert old drawings into digital files as well as a reluctance of keyholders to release information. Therefore, while the measurement of plans was achieved, data collection was more time consuming and arduous than anticipated. For example, both the RLH and St. Thomas' plans took over nineteen months each to locate. Consequently, the case study's sample was limited insofar that it was not feasible to extend pre-1990 research to UCLH and Chelsea and Westminster case studies. Having relocated numerous times since 1840, data collection limitations guided the thesis to not research these pre-1990 case study plans. This limitation directed the research to explore a smaller case study sample, which may have limited thesis findings.

The second limitation arose from the quality of collected material. Many pre-1950 drawings were unreferenced with no scales, dates or drawing information inscribed. Additional time consuming analyses was required to make sense of discrepancies between sets of plans. For example, the 1832 RLH plans were found to be inconsistent when scaled to match 1900 drawings. As the building remained unchanged between 1832-1900, the decision was made to base all drawing measurements from the detailed set of 1900 plans. This limitation may have skewed some results.

The third limitation regards the unavailability of full sets of hospital floor plans. This added further procedures to the data analysis process. Calculations were produced from a combination of plans, sections, literature searches and photographic data. This limitation reduced the scope of data analyses and led to inconsistent findings at times. Generally, major problems exist for the collection of NHS hospital data. This study contributes to filling this gap in medical planning knowledge.

A self-created methodology directed the study, which may have been bias. However, this fourth limitation is based upon established scenario logics. This method was chosen to enhance the trustworthiness of scenarios by providing alternative futures with a broad spatial vision rather than a limited perspective of developing medical ETs.

The fifth restriction regards future medical equipment information, which remains limited in 2013. In comparison, a plethora of scientific information exists for future medical practices. For example, scientific data upon pharmacogenomics is published widely but its clinical delivery is not so explicit from literature. This limitation restricted insight into the visualisation of future hospital space.

3.10 Chapter conclusion

This chapter identifies the research design adopted to deliver the current study. This is a single future-orientated ‘prospective’ methodology and mixed-methods approach. The self-created research design divides the thesis into three research phases where each is dedicated to exploring the objectives set out in Chapter 1. In a bid to highlight an alternative perspective of medical technology’s influence on future urban acute hospital space, the thesis creates a new methodology derived from Krawczyk and Ratcliffe’s future studies theories. On this basis, a quantitative case study methods approach was incorporated for data collection and analaysis. This is followed by scenario creations that visualise future hospital spaces that incorporate medical ET findings. The first of four thesis objectives is to prove technology’s relationship with hospital space. As all journeys *begin with a single step,* the first process of the ‘prospective’ methodology is explored next in Chapter 4.

Chapter 4: Historical influences of UK hospital space

“Present-day hospitals reflect a combination of the legacy of the past and the needs of the present”

(Healy & McKee, 2002:14)

4.0 Introduction

Part II is a research phase dedicated to confirming technology's relationship with hospital space. Chapter 4 focuses on meeting this first objective by presenting a historical review of British hospital space. Revolutions and intertwined elements are mapped through the examination of past and present design factors to provide an understanding of evolving spatial influences that constitute current NHS hospital design. The chapter begins with an exploration of organisational and medical design factors that trace medical planning events and subsequent spatial revolutions since 1600. Thereafter, a critical assessment of architectural influences exposes post-1850 events that are crucial to revolutionising British hospital space. Chapter findings reveal three sets of important information: (i) a list of influences that impact directly on hospital space formation; (ii) a mapped evolution of medical planning from which to examine technology's impact on hospital space in Chapter 5; (iii) relevant trends to assist with future-proofing hospital space in Chapter 8's scenario creations.

4.1 Organisational influences: The NHS

This section introduces the NHS as an organisational influence to explain its exclusion as a dominant hospital design factor and timeframe chosen for this study's initial spatial exploration. In recognising the NHS's dominant role in British public healthcare, two perspectives - pre and post NHS establishment (1948) - are drawn to examine how organisation imposes on hospital space.

4.1.1 Pre 1948: Royal and voluntary hospitals

Outlined in Appendix D.1, the origins of British healthcare were dominated by ecclesiastical power, which ended abruptly after Henry VIII's enforced dissolution of monasteries (1536-40). This reorganisation of managerial power devastated British healthcare provision[1] (Richardson, 1998:1). The outcome witnessed the closure of all infirmaries throughout the UK. In London, the closure of St. Bartholomew's, St. Thomas' and St. Mary's without Bishopsgate (1539) caused London's impecunious to suffer colossal healthcare losses (Barry & Carruthers, 2005:16-8). However, Henry VIII's financial act of greed ironically transformed the organisation of British healthcare. A twofold revolution resulted from accumulated events. The first revolution witnessed the opening of desperately needed new hospital buildings. Four fee-paying Royal Hospitals were established by The Crown in response to government pressure concerning the City's dire healthcare requirements[2]. Two remain functional today - St. Bartholomew's and St. Thomas'- but have outgrown their original hospital premises. Such prototypes possess four hundred years of cocooned typological information. Subsequently both were nominated for case study research in Chapter 6. The second revolution marked the end of ecclesiastical domination and the beginning of new methods for organising healthcare. These were the 'Royal' and 'voluntary' hospital organisations.

No hospitals existed outside the City of London by 1700. In contrast, City philanthropy had resulted in the establishment of numerous charitable infirmaries in London City[3]. With funds barely covering medical care expenses, 'voluntary' hospitals were located originally in humble rented accommodation, such as, the RLH, Westminster and Middlesex hospitals[4]. These privately managed and funded secular structures revolutionised hospital management (Barry & Carruthers, 2005:58,102). The power of healthcare organisation was diverted to lay people for the first time introducing new

---

[1] Henry VIII's tax policy was introduced to pay for the expenses of the French war and his extravagant lifestyle. However, tax money 'collected for reconstructing new hospitals' was never transferred.

[2] Bought and administered by the City of London (1547-51), the four hospitals included: Bethlem; Bridewell; St. Thomas's; St. Bartholomew's. (*St Bartholomew's Hospital*, St. Bart's Archives).

[3] 17th century trade and commerce flourished resulting in a new wealthy middle-class who wished to help the poor by establishing hospitals.

[4] Westminster (1720), Guy's (1724), St. George's (1733), The London (1740) and Middlesex (1745).

roles into the process of designing hospitals. The success of the voluntary hospitals is represented architecturally by the existence of mid-19th century typologies throughout the capital city (Richardson, 1998). Hence, these voluntary hospitals are noted as extremely significant, acting as precedents to contemporary NHS management and NHS hospital design. However, by the 1940s, hospital running costs had become excessive, beyond philanthropy and patient fees (Porter, 2006:209-10). An alternative solution was necessary as existing organisational structures proved unfeasible financially.

4.1.2 Post 1948: The NHS

Throughout the late-1800s and the duration of both world wars, state involvement in public healthcare had become increasingly expectant. Assisted by the escalating expenditure of medical treatment and salaries, the provision of healthcare became a political affair. True to their electoral campaign, the new Labour government passed through parliament the most important UK healthcare act ever - the *1946 NHS Act* (Willcocks, 1967:28). The impact of this monumental health act amalgamated all existing public hospitals and their estates into one unified organisation - the NHS (1948). This new healthcare system suffered from post-World War II (WWII) financial shortages as government budgets only allowed for housing and education construction (Pickstone, 2006:290; Watkin, 1978:59). The outcome was rather non-eventful as the *1946 NHS Act:*

> Created no new hospitals, trained no new doctors, brought no new drugs or methods of treatment into being (Watkin, 1978:1).

Essentially the NHS's formation modified the managerial and financial organisation of British social healthcare. Other organisational acts followed, notably *1973 NHS Reorganisation Act*, *1999 Health Act* and *National Health Service Act 2006* (current NHS regulation), but all were concerned with changing internal management only (The Charity Commission for England and Wales, 2011:1-7). While NHS events were expected to be architecturally revolutionary, findings reveal the NHS establishment did not affect hospital design essentially. Estates were sold or re-organised within the NHS system but no new hospitals resulted from the unification of socialised care. This redirected this study's research to widen its historical perspective. Details are elaborated upon in section 4.2.

By the mid-1990s, the NHS remained the organisational structure for providing British social healthcare. Spiralling costs for maintaining hospitals became financially onerous, far beyond taxpayers' fundable scope (Leach, 2007:22). Alternative financial methodologies were introduced to rebuild the NHS estate, which included Local Improvement Finance Trust (LIFT) and PFI processes. Over the past decade, newly constructed NHS acute hospitals have been delivered predominantly by PFI, altering NHS capital estate ownership significantly. At a time when most NHS hospitals needed renovation (2000s), PFI was a solution that resolved the critical necessity of rebuilding the NHS's deteriorating estate. While negative opinions about PFI products are expressed throughout the architectural profession (see Figure 4.1), this study asks; was there an alternative solution to address the dire hospital needs at that time? Generally, public discussions concentrate on improving or abolishing the PFI process but procedures are not this study's particular focus. Instead, this main concern is the reality of PFI NHS hospitals and their ability to cope with future spatial change.

Richard Rogers called for the government to abandon PFI and a return to 'a more direct appointment of architects'

John Cooper: 'Everyone...acknowledges that PFI in its current form is effectively dead, and a new form of procurement needs to be devised'

Jack Pringle: 'It has produced very poor results in terms of design, cost control and manageability, and now it can't even finance itself'

Figure 4.1 Published opinions about the PFI process by leading UK architects (Winston, 2009:1).

4.1.3 Analysis of organisational findings

Three periods and two revolutions emerged from an analysis of organisational findings (see Table 4.1). The significance of both transformations represents a major trend in organisational change. For example, ecclesiastical care was organised on a massive institutionalised scale. Thereafter, healthcare was transferred to a segregated network of Royal and voluntary hospitals. However, the original status of a large institutionalised organisation was reinstated by the NHS's establishment, which leads the thesis to suggest that, considering the NHS's current crippling financial budget, the future NHS solution is to segregate their mass organisation. Historically, organisational transformations were not embodied architecturally but if segregation were to happen in the near future, the potential hospital medical planning ramifications would be far-reaching. For example, shared services and medical equipment, such as, CTs and MRIs, are co-located for current financial and staffing efficiencies. Therefore, equipment and staff would need to be duplicated but space for this change is unaccounted for in PFI hospitals. This alternative NHS scenario requires a spatial examination which is beyond this thesis' scope.

Five of the seven organisational events recorded had architectural implications (see Appendix D.8). Therefore, one could determine organisation to be a dominant hospital space driver. However, further investigations charted the same data against the availability of financial investment (see Table 4.2). Findings revealed that finance was present 100% for all organisational events. This identifies a dependent relationship co-exists between organisation and finance. The recent national hospital rebuilding programmes (1960s/2000s) support this argument fully as the transformation of NHS hospitals would not have occurred without major financial injections.

Organisational Period	Time scale	Revolution
Christianity to Voluntary Hospitals	(300-1700AD)	(i) Shift from ecclesiastical power to Royal or voluntary organisations
Voluntary Hospitals to NHS	(1700-1948)	(ii) Unification of British hospital management under the NHS.
Post-NHS	(1948+)	

Table 4.1 List of organisational findings: Timescales and revolutions (see Appendix D.7).

	A. Organisation	B. Financial investment	C. Spatial impact	D. Analysis
Pre- NHS(1948)	Greeks	Not stated	No. A number of existing temples	No development
	Christianity	As their power expanded, finances accumulated	Yes. Infirmaries built alongside monasteries	Increased numbers but no innovation
	Reformation	No money available	No. All hospitals closed	Organisational influence only
	Royals	City of London bought Royal hospitals	Yes. Rented in existing architecture of Palladian styled buildings	Mainly rented accommodation but Royals were organisationally significant
	Voluntary	Charitable fund raising brought in financial support	Yes. In rental properties until the mid-19th century	Rented first until finance available to build
Post-NHS(1948)	NHS	Money injected from government in *1962 Hospital Building Plan*	Yes. 10 year hospital building programme	Influential only when money was available
	NHS/PFI	PFI process created a new source for financing	Yes. 10 year PFI hospital building programme	Influential when money was available

Table 4.2 Analysis of findings: Financial investment included (see Appendix D.8).

Generally, until 1850, organisational influences were architecturally numeric based on hospitals opening and closing rather than instigating spatial evolutions. The establishment of the NHS proved equally non-eventful as no new hospital buildings resulted. Therefore, while a link was found to exist between organisation and architecture, a co-dependency on finance identifies the NHS and organisational influences not to be dominant drivers of hospital space within this study’s context.

4.2 Medical influences: Post-16th century

The previous section's revelations inform the timeframe for exploring medical influences. As the NHS establishment was defined as a non-event in the history of British hospital design, the research was redirected from a pre- and post-NHS examination. Instead, an extensive search of events was undertaken dating back to 400BC to identify a relative period that corresponds with the study's investigation of hospital space (see Appendix D.1-6). Findings reveal most pre-1600 hospital design events are irrelevant to the study. Therefore, this section analyses a conflation of post-17th century revolutionary medical events. Four of the five medical influences identified in section 3.1.2 are examined individually in sections 4.2.1-4. Thereafter, a spatial analysis of all medical influences is discussed to identify historical key drivers responsible for reconfiguring hospital space.

4.2.1 Medical knowledge: The development of western medicine

The development of western medical knowledge is interwoven with numerous internal and external influences. Seven medical knowledge events inform the development of post-16th century hospital space: (i) the end of ecclesiastical power; (ii) Italian Renaissance; (iii) printing technology developments; (iv) Industrial Revolution; (v) worldwide movement of medical students; (vi) 19th century evolution of hospital functionality; (vii) 20th century molecular exploration.

The first event is the end of ecclesiastical control over healthcare (1539) which, in its absence, demolished the barriers restricting medical exploration and innovation. This monumental event initiated the growth of medical knowledge which, in turn, revolutionised Galen's millennium-old theories of classical humorism[5]. This event was

---

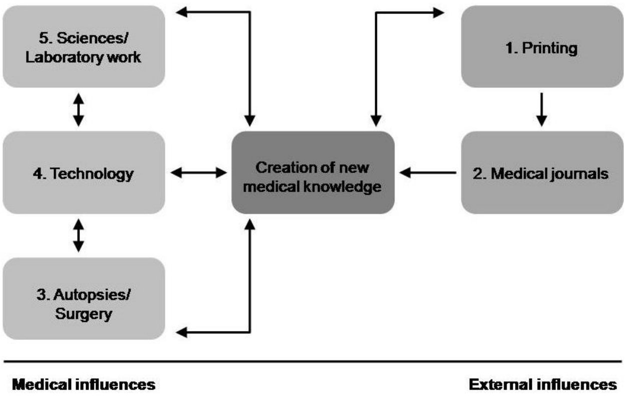
[5] See Glossary.

further assisted by another fortuitous opportunity; the great eruditional epoch of the Italian Renaissance. This second event encouraged autopsy exploration, which assisted in founding new anatomical knowledge and the eventual instigation of Galenical doctrines to be challenged as naive and incorrect. From these revolutionary events unfolded new discoveries that transformed the extent of medicine. This was followed by the New Sciences[6] and Age of Enlightenment[7], which expanded medical knowledge further, for example, William Harvey's discovery of the blood circulatory system (Porter, 2006:136-214).

The third event was the advancement of printing technology which expanded the availability of publishing. The correlation between medical experimentation and written knowledge was improved vastly through increased productivity. As recorded:

> The introduction of printing in England in 1476 marks a different, and well-documented era (Levere, 1982:40).

This technology development revolutionised the ability to gain access to vital medical information (see Figure 4.2). As a result, 14th and 15th century medical knowledge expanded extensively based on the large increase in English scientific texts (Taavitsainen & Pahta, 2004:1).



1 - Printing
2 – Medical journals, etc.
3 – Autopsies/Surgery
4 – Technology
5 – Sciences/Laboratory work

Figure 4.2 Relationship diagram of findings: Impact of printing.

---

[6] Based in 17th century Italy, The New Sciences fundamentally established body functionality.
[7] The Age of Enlightenment explored general anatomy during the 18th century.

Volumes of Printed Titles	
Year	**Titles**
1518	71
1519	111
1520	208
1523	498
1665-1790	1052

Volumes of Printing	
Year	**Prints**
1436-1536	420
1736-1816	22,500

Table 4.3 Tables of listed printed volumes (Kronick, 1962:60,73).

The impact of new printing technology is evident in the number of printed volumes between 1436 and 1816 (see Table 4.3). As Steiner & Phillips argue, over 700 journals were established in America, Canada, and Great Britain by 1830. Of these, '2 newspapers and 3 journals were medically orientated', one of which - The Lancet - remains central to current medical practice[8] (Steiner & Phillips, 1993:1). These figures contrast radically with the 9th century's total of 1000 books of knowledge (see Appendix D.1). This third event provides insight into the influence of new technologies on the development of medicine. In this case, new communication systems dispersed information that led to new medical knowledge and practices.

The fourth event was the Industrial Revolution and its direct influence on 19th century medical innovativeness. New inventions, processes and technologies filtered through to impact on the medical field. For example, new scientific knowledge led to the discovery of X-rays, anaesthesia and aseptic treatments (Barry & Carruthers, 2005:44). These discoveries revolutionised diagnostic and surgical exploration adding new dimensions to medical knowledge.

Fifth, by 1800, France had become a hub for surgical innovation while German laboratories led the field of pathological science. Students worldwide flocked to Europe to study within these educational institutions. Upon graduation, they returned to their

---

[8] The two newspapers included The Lancet (1823) and London Medical Gazette (1827). The three journals included Edinburgh Medical and Surgical Journal (1800), British & Foreign Medico-Chirurgical Review (1824).

native countries to disperse their medical discoveries within new self-established specialists' hospitals (Porter, 2006:160-3). The significance was expanse insofar that, for the first time, medical knowledge became dispersed on a global platform made possible by improved communications, such as, medical journals.

The sixth event was a revolution in hospital functionality which occurred in the 1800s. Hospitals evolved from places of care into centres of medical information. With newly introduced pedagogical methodologies, hospitals became pivotal to institutionalised knowledge. Clinical instruction became central to the educational curriculum where medical students followed their tutors around wards and operating theatres (Porter, 2006:187-8). Additionally, hospitals themselves became sources of knowledge where physical examinations were allowed for the first time. Physicians gained new medical knowledge from accessing large populations of varied sick patients.

> Since the physician had far more control over the patient in the hospital setting, medical science progressed more rapidly there (Miller & Swennson, 2002:44).

This ability to explore, monitor and treat disease in 19th century hospitals became central to discovering new anatomical knowledge and the development of the modern hospital.

The seventh event bypassed the accumulation of all previous medical progression. This was 20th century cellular exploration which revolutionised pharmaceutical and molecular sciences. For example, the discovery of DNA structures, penicillin and paracetamol, represent 20th century medical innovation that has increased life expectancy and the quality of human lives (Pickstone, 2006:289; Rosenfield&Rosenfield, 1969:5). At present, molecular exploration continues at the 'nano' scale of metabolism to expand medical knowledge and the discovery of new anatomical functionalities.

Spatial outcomes, resulting from medical knowledge progression, proved inconsistent. For example, while revolutions occurred in medical knowledge from 1600 onwards, purpose built hospitals only existed post-1800s. From here on in, the outcome of the Industrial Revolution formed new specialist disciplines and medical specialities which increased space for functionalities as well as establish new specialist hospitals. Later, as hospitals became pedagogic centres, the demand for additional space resulted in the construction of many teaching hospitals (UCLH,1834). However, the arrival of 20th century cellular exploration deeply affected hospital space. Laboratory areas were increased to cater for a broader range of treatments. In doing so, additional space to all departments resultd while medical planning complexities increased as more patients were admitted.

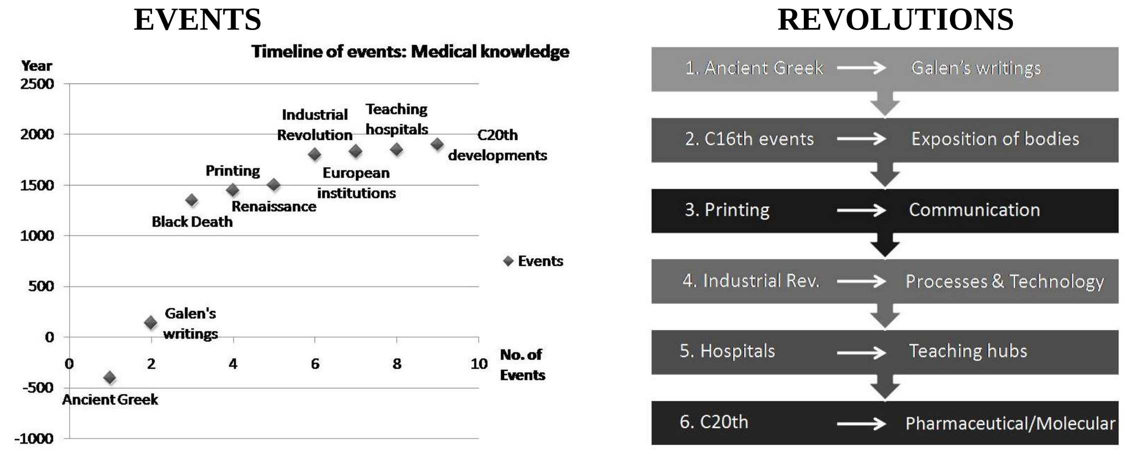
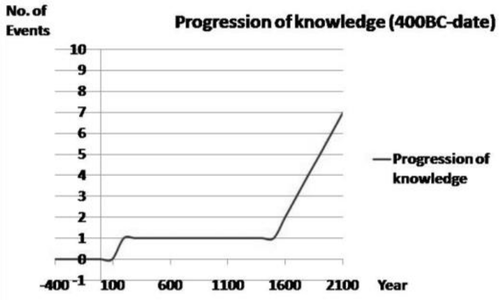


Figure 4.3 Medical knowledge findings: List of events and revolutions (400BC-date)



List of events (400BC-date)	Spatial implications
1. Ancient Greek	None
2. Galen’s writings	None
3. Black Death - autopsies	None
4. Printing	None
5. Renaissance	None
6. Industrial Revolution	Yes
7. European institutions	Yes
8. Teaching hospitals	Yes
9. C20th developments	Yes

Figure 4.4 Medical knowledge findings: Graphed of events and list of spatial analysis (400BC-date).

Findings from 400BC-2012 are charted in Figures 4.3-4. Nine events and six revolutions were recorded but spatial implications remained constant (four) between pre and post-1600 periods. Therefore, the thesis determines; a shared status of activity between post-1600 hospital space and medical knowledge does not establish the latter as a dominant driver of hospital space. This decision is based on a lack of spatial planning implications prior to 1800 as no medical planning evolutions emerged particularly between the Renaissance and Industrial Revolution. On this basis, the thesis identifies the emergence of new medical knowledge is as an early indicator of hospital spatial change.

4.2.2 Medical practice: Development of clinical and acute care

Hospitals were identified as places for recuperation in section 4.2.1 where Galen's classical humorism dominated healthcare until the 1800s. Only basic medical treatments were administered, for example, cupping, cutting and sweating (Barry & Carruthers, 2005:144-5). Designated spaces for specialist medical functionality were, therefore, not required at this time. For the affluent, the same humoral care[9] was delivered by physicians within clients' homes. This characterises the number and types of patients within pre-19th century hospitals. While historically non-eventful, two medical practice events have occurred since 1600. Both occurrences were responsible for revolutionising the course of modern medical practice.

The first revolution unfolded as new medical knowledge accumulated by the 1850s. Galenical practice was replaced with a new model of care: the 'clinical gaze' (Foucault, 1989:58-62). This change in medical theology revolutionised the centuries-old humoral practice from one of care to diagnosis and treatment that focused on disease rather than

---

[9] Reference to the practice of Galen's classical humorism.

patient ailments. This revolution was enormously significant as it established a new medical agenda. The 'clinical gaze' remains the philosophical basis of contemporary western medicine and practice.

Continued growth of 19th century medical knowledge lends itself to the second medical practice revolution. New knowledge directly affected medical practice to become segregated and specialised. However, it wasn't until the 1930s that a new discipline was established in accordance with acuity level. This was the emergence of acute care practice, which as a recent development, has developed quickly into a complex discipline (see section 4.2.3).

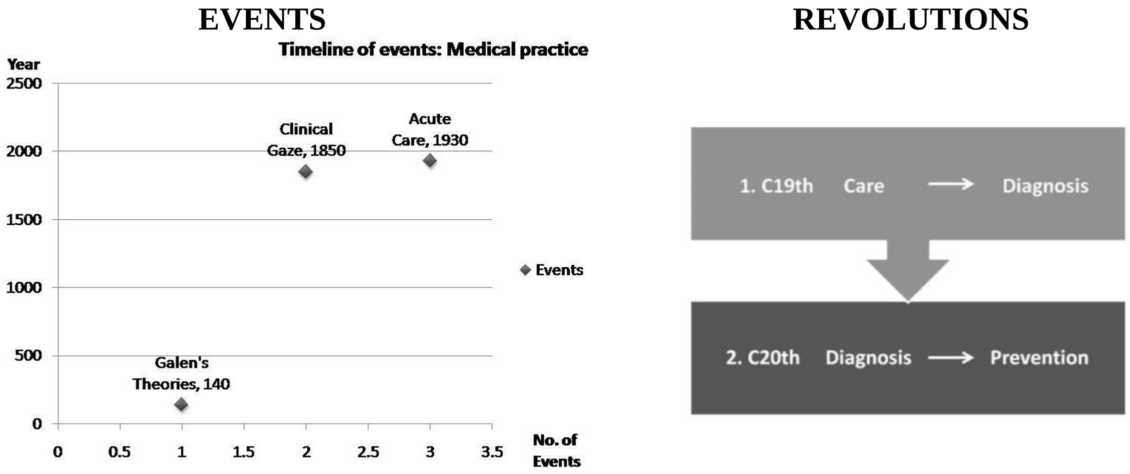


Figure 4.5 Medical practice findings: Events and revolutions (400BC-date).

Only three revolutions were revealed from analysing 2400 years of medical practice (see Figure 4.5). Previously alluded, the outcome of uncontrollable external factors stagnated healthcare practice for many centuries. Therefore, while in existence for over two millennia, the thesis identifies medical practice as evolving only since the mid-19th century. However, findings indicate that a relationship exists between a change-in-practice and hospital space formation. For example, after the clinical gaze transformed the medical agenda, the number of hospitals boomed. Each contained dedicated clinical spaces for new medical practices, such as, operating theatre (OT) rooms at the RLH (see section 6.2). Similarly, no acute care facilities existed in pre-1930s hospitals but since the introduction of an NHS acute care service, large specialised acute hospital buildings have come into existence. Both outcomes determine that spatial implications result from changes in medical practice. Hence, the thesis identifies medical practice as a dominant driver of hospital space.

4.2.3 Delivery of medical practice: The impact of British services

This section focuses on the delivery of medical practice to understand its influence upon hospital space. Taken from the perspective of British care, the discussion of medical delivery is divided into pre- and post-NHS periods. Six events are identified, with five considered as revolutionary, to comprehend the significance of delivery upon the configuration of hospital space.

(i) Pre-NHS

Physicians delivered Galenic practice for numerous centuries (140-1850s). Spiritual, rather than physical, care was delivered in ecclesiastical infirmaries. Thereafter, Royal and voluntary hospitals delivered humoral palliative care but unlike the fee paying Royal hospitals, voluntary hospitals offered free care, such as, at the Royal Free Hospital, London (Barry & Carruthers, 2005:73; Richardson, 1998:5). Free healthcare resulted in great demands which evolved voluntary hospitals substantially:

> From a handful of infirmaries which served a minority of the population into a network of institutions which are central to the health and welfare of the entire country (Richardson, 1998:vii).

Social attitudes were overturned when increased patient survival rates and improved environmental conditions gained voluntary hospitals a good reputation, as attendance at hospitals was socially unacceptable prior the late-1880s. This change instigated a new trend where affluent patients began attending voluntary hospitals. The outcome changed the patient type and influenced the quality of hospital services and environments (McKee & Healy, 2002:17). By 1948, both Royal and voluntary hospitals had become strategic to delivering British public healthcare.

Improvements to 19th century transportation impacted on the extent of healthcare delivery indirectly. For example, patients without access to hospitals could now travel by train to be treated in London. More notably, transport was incorporated into the delivery system for the first time through the activation of the *1879 Public Health Act*. Ambulances were introduced to transport contagious patients to hospital as part of a public health quarantine process.

> One benefit was that the Act permitted the board to provide horse-drawn carriages for the transport of patients to hospital to reduce the use of public transport and thus the spread of the disease....Ambulance stations were created at the hospital, with accommodation for the nurses and coachmen as well as the ambulances and horses (Barry & Carruthers, 2005:169).

This rapid transportation of sick patients to hospitals introduced an emerging concept for 20th century healthcare. Nevertheless, palliative care remained dominant in British hospitals until another important act was passed in response to WWII casualty forecasts. The *1939 Emergency Medical Service (EMS) Act* set about unifying medical staff amongst all London hospitals to create a united network of services (Rivett, 1986). This new model for delivering care was significant from two perspectives: (i) as a precursor to the NHS system; (ii) as a concept for delivering future acute care.

(ii) Post-NHS

The most revolutionary event in delivering British public healthcare was the NHS. The delivery of care became nationalised into one organisation from a staffing and managerial perspective. Additional revolutions were experienced in the delivery of medication, surgery and diagnostics (Watkins, 1978: I). Since 1948, the NHS can be accredited with developing the delivery of British public acute care. Since its origins, the delivery of acute care has affected the number, size and medical planning of NHS hospitals enormously. The NHS currently operates 166 previously non-existent British acute hospitals. Equally since 1948, delivery has evolved to become a ‘patient focused care’ essential to administering quality care since the 1970s (DOH, 2007:1). Established in the NHS’s *1991 The Patient Charter*[10], patient rights and experiences in hospital are currently central to delivering NHS care which is palpable from the NHS’s recent intent to deliver care in 100% single patient bedrooms (such as, Pembury Hospital, Kent, 2010). Currently, NHS care is delivered predominantly at clinics, acute and DGHs while home care is delivered through numerous care-in-the-community programmes. However, the recent arrival of computer and internet technology is evolving the nature of delivery to one of mobility. For example, telemedicine and telehealth are new methods for delivering NHS care which are revolutionising the role of NHS hospitals profoundly.

	Events	**Revolutions**	**Spatial impact**	
1.	Establishment of Voluntary/ Royal hospitals	Change in organisation for delivering care	Not directly, overtime	**Pre-NHS**
2.	*1879 Public Health Act*	Concept of transferring patients to hospital by ambulance	Yes, space for nurses, coachmen and horses added	
	1939 EMS Act	Development of acute care practice begins	Yes, after the 1940s	
3.	NHS Act (1946)	Nationalised the delivery of UK care	None	**Post-NHS**
4.	*1991 Patient Charter*	Patient focused care	Yes, but only starting to filter through	
5.	Development of technology and internet	High-tech UAT care developed	Yes, mobility is changing delivery	

Table 4.4 Medical delivery of care: Historical analysis post-1600 findings.

---

[10] Introduced by the then Conservative government, to give access to services and information with personal consideration and respect to patients (Hogg, 1999:179).

Section findings indicate that medical delivery impacts on hospital space strongly (see Table 4.4). The thesis, however, determines this influence is not a dominant design driver in spite of findings. An analysis reveals that delivery relies upon other events to instigate spatial change. For example, NHS acute care delivery was an outcome of the *1939 EMS Act* and not an outcome of progressing medical practices. For this reason, the thesis recognises the delivery of medical practice is a dependent design factor that impacts on hospital space in the long-term.

4.2.4 Medical processes: The concept of separated care

The significance of medical processes within the history of hospital space are taken from two perspectives of separated and non-separated care. Three important events are revealed as revolutionary and support medical processes as being a dominant driver of hospital space.

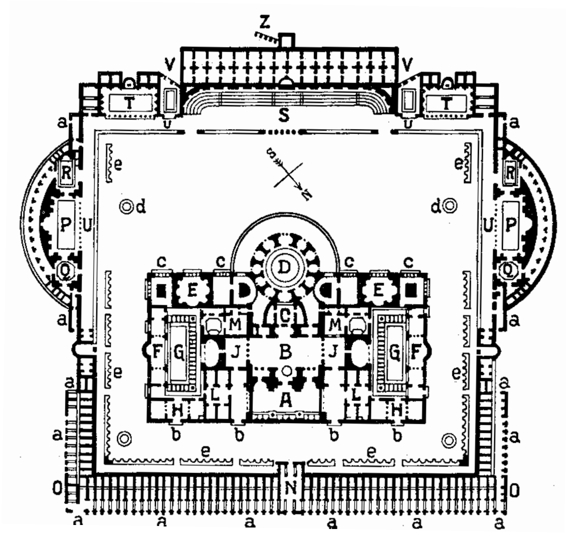
The concept of separated medical care is not a recent development. The Ancient Greeks and Romans practised segregation between males and females as well as hot and cold treatments. Proof of these processes is exemplified in the architectural ruins of the Baths of Caraculla, Rome (see Figure 4.6). However, this process was overturned by the domination of ecclesiastical non-separated care:

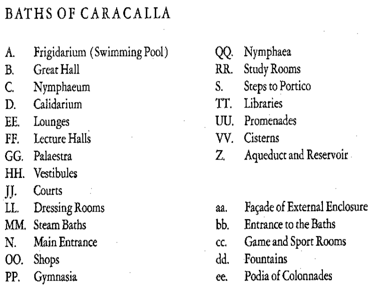
> Treatment was very limited; instead, caring, compassion, and spiritual comfort were emphasized (Miller & Swennson, 2002:40).

The process of non-segregation was reflected spatially in the form of large open rooms, such as, the layouts of pre-1600 monastic infirmaries represented typically in Figure 4.7. Alternatively, physicians delivered classical humorism where simple functionalities were exercised. None required a degree of separation for delivering Galenic medicine. One exception existed during medieval times (400-1400s) for those with infectious diseases. This segregation, however, did not take place within infirmary buildings, as contagious patients were not permitted into these establishments. Instead, infected patients were sent to leper 'hospitals' or 'lazar houses' on the outskirts of towns (see Appendix D.5).

> Lepers were accommodated in secluded communities of separate cottages with detached chapels (Richardson, 1998:1).

British recordings of lazar houses date from pre-Norman times and continued until their use expired after the 1400s (Barry & Carruthers, 2005:9-12). Thereafter, the next and latest revolution in medical processes evolved from a joint accumulation of three significant events.




BATHS OF CARACALLA

A.	Frigidarium (Swimming Pool)
B.	Great Hall
C.	Nymphaeum
D.	Calidarium
EE.	Lounges
FF.	Lecture Halls
GG.	Palaestra
HH.	Vestibules
JJ.	Courts
LL.	Dressing Rooms
MM.	Steam Baths
N.	Main Entrance
OO.	Shops
PP.	Gymnasia
QQ.	Nymphaea
RR.	Study Rooms
S.	Steps to Portico
TT.	Libraries
UU.	Promenades
VV.	Cisterns
Z.	Aqueduct and Reservoir
aa.	Façade of External Enclosure
bb.	Entrance to the Baths
cc.	Game and Sport Rooms
dd.	Fountains
ee.	Podia of Colonnades

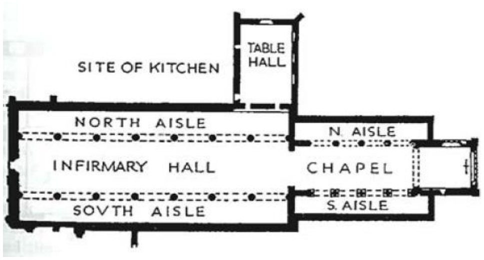


Figure 4.6 Left: Baths of Caraculla (250AD) organised different treatments and ailments through the use of sophisticated planning and technology (Furneaux Jordan, 1991:53). **Figure 4.7 Right:** 12th century Monastic Infirmary, Canterbury Cathedral (Barry & Carruthers, 2005:1).

The first event resulted from a change in disease from plagues to other contageous illnesses. These included smallpox and cholera which were sourced allegedly from 'miasma'.

> In the mid-eighteenth century, the prevailing theory of the causality was the miasmatic or zymotic theory which held that illness was the result of miasma or 'bad

> air'...and the deterrent to miasma was the circulation of plenty of fresh air (Miller & Swensson, 2002:42).

As a result, 18th century military hospital design, 'the most advanced medical thinking of the period', created a new typology for the functional treatment of miasma[11]:

> The Admiralty hospital was built as a series of detached pavilions connected by an open arcade, thereby exposing patients to the maximum amount of natural ventilation (Miller & Swensson, 2002:42).

The outcome of this event was twofold in revolutionising the process of care and hospital space: (i) it re-introduced the concept of clinical separation; (ii) infectious patients were included in hospitals for the first time. In contrast, since no public hospital construction existed for another one hundred years, general hospitals:

> Restricted themselves to fairly minor complaints likely to respond to treatment, and they excluded infectious cases...Separate fever hospitals were, however, set up for those with contagious diseases[12] (Porter, 2006:186).

Eventually the 'military' model was incorporated into 19th century British public hospitals. The most noted being St. Thomas', London with its 'miasmatic' orientated Nightingale Wards (see section 4.3.1).

The second event emerged during the early European Renaissance where a degree of separation was introduced at the Hotel Dieu, Paris (see Figure 4.12).

> Patients were classified and separated according to type and severity of illness, and there was a separate unit for women recovering from childbirth. The hospital was divided into various departments, each governed by a head (Miller & Swensson, 2002:41-2).

Mapping the first form of clinical departmentalisation within contemporary European hospital design, the Hotel Dieu's introduction of new disciplines marks a distinct change in hospital functionality. This conceptual manner for a 'hospital' would take many years to emerge within Britain (post-1850s). An array of events allowed for the medical planning of British hospitals to develop finally. In response to new anatomical knowledge and the clinical gaze's effect upon delivery, numerous specialist hospitals

---

[11] A military hospital at Stonehouse, Plymouth (1762) is the best typological example designed with miasma in mind at this time.

[12] An example of a fever hospital included the House of Recovery, London (1801).

became established throughout London City[13]. However, specialised care within London's general hospitals was hindered by staff monopolisation whose hostility and distrust towards specialists banned specialist disciplines from all general hospitals (Richardson, 1998:34). The outcome was no departmentalisation until the late-1800s. Physicians revoked this status eventually to allow for specialist care within general hospitals (Barry & Carruthers, 2005:184). This major event revolutionised British care and medical planning since the 1870s.

The third event was instigated by medical knowledge expansion which replaced humoral care. This diverged medicine into numerous medical specialities of body parts, diseases and age groups. The outcome segregated medical practice to produce new disciplines, professions and functionalities. Each expanding medical care component required new space, for example:

> In an 1889 survey most general hospitals had established out-patient clinics for skin, eyes and ENT, but only women and ophthalmology had small in-patient units (Barry & Carruthers, 2005:188).

Even during the short period of 1870-90, departments grew in size and numbers. All events map the beginning of the latest trend for separated care. Spatial and functional growth continued until after World War I (WWI) where 'departments for specialised treatment multiplied rapidly' mapping further medical planning developments (Richardson, 1998:11). New 20th century departments included Imaging, Radiotherapy and Nuclear Medicine, Catheterisation Laboratories, ICU, Coronary Care Units, Endoscopy and Neurology. All are classified as high-tech departments that deliver specialised care. This process of separated care remains current practice throughout NHS hospitals.

---

[13] Graduates wishing to work in specialist disciplines could not find work in general voluntary hospitals and were forced to open their own specialists' hospitals. As a result by 1875, 36 specialist hospitals existed in London.

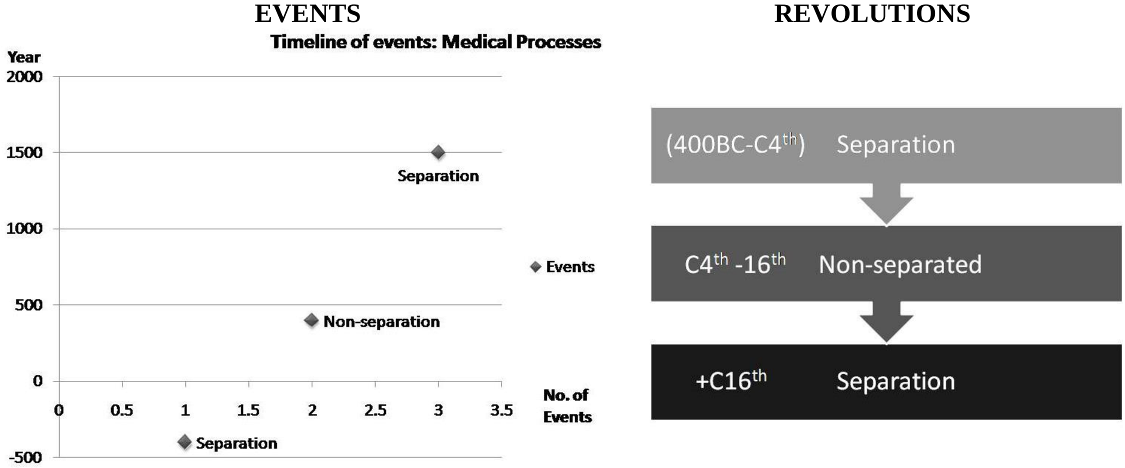


Figure 4.8 Medical process findings: Events and revolutions (400BC-date).

Three revolutions are revealed for medical processes which interchange between separated and non-separated care (see Figures 4.8). Both forms of medical process demand drastically different spatial requirements as represented by monastic infirmaries and the Baths of Caraculla. The latter typology correlates with present medical planning complexities which are linked significantly through the same use of separated care. For example, the latest medical process trend has led to the intricate division of hospital space which is similarly reflected in Caraculla's spatial planning. This finding supports that medical processes influence spatial configuration. Current segregation has resulted from three revolutionary events: the influence of 18th century military design; Hotel Dieu's 'hospital' concept; the accumulation of numerous post-1850s events. In each case, all medical process events impacted on hospital space directly so much so that new medical planning models were created to respond to change. Hence, the thesis determines medical process is a dominant driver of hospital space.

4.2.5 Analysis of medical influences

A spatial analysis of section findings completes this examination of post-1600 medical influences.

The discussion upon medical knowledge as a design influence raises two important issues. The first issue is the statistical finding that 55.6% of events occurred since 1600 (last 17% of researched timeframe) (see Appendix D.9). While this data is not a quantitative measurement, the analysis drawn from findings is that the volumetric measurement of medical knowledge has grown immensely since 1600. For example, access to 9th century knowledge was documented as ‘1000’ books, in comparison with Feynman’s 1959 calculation of ‘24 million volumes of interest in the world’ (Nutton, 2006:62; Feynman, 1960:24-5). New knowledge was identified as instigating medical innovation which led to the requirement of new hospital spaces. The second issue regards the stagnated status of pre-1600 medical knowledge which is reflected similarly by a lack of hospital spatial innovation. These similarities could be interpreted as a direct relationship between medical knowledge and hospital space. However, the thesis identifies why medical knowledge is not dominant in influencing hospital space. Firstly, inactivities in hospital space and medical knowledge were not linked uniquely during The Dark Ages. Ecclesiastical domination restricted innovation across the whole of European society. Secondly, the Renaissance and Industrial Revolution were medically innovative but 17th-18th century British hospitals are not exemplified architecturally. Contextually, if a revolutionary article on surgery is published in *The Lancet*, this new knowledge will not directly affect hospital space as new surgical practices will need to be created first. The impact on space will result from a change in medical practice instead. Therefore, the thesis determines that a direct link does not exist between medical knowledge and hospital space. Three medical planning trends identify medical knowledge as:

(i) Not a direct design influence of hospital space

(ii) Central to instigating other medical influences

(iii) ‘Stage 2’ in configuring hospital space (see Figure 4.9: Example 1).

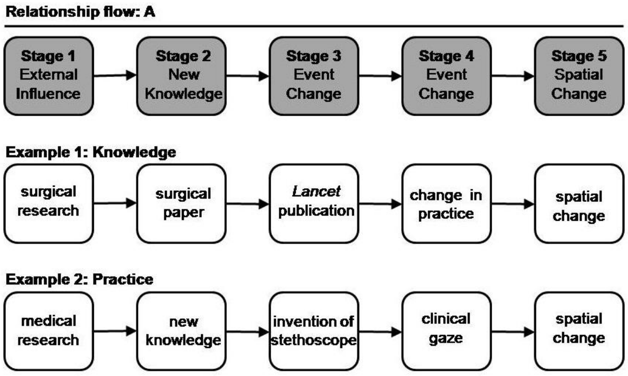


Figure 4.9 Relationship flow diagram A: Analysis of medical knowledge and practice.

Only three medical practice revolutions emerged between 400BC-2012. In each case, the event was so profound it transformed the course of medicine. With 66.6% of events occurring in the last 8.8% of researched time, it was determined that post-1800 medical practice events were central to overturning the methodology and philosophy of 19th century medicine (see Appendix D.10). In continuing this trend, the next revolution will cause a similar major change by deeply affecting the existing model of medical practice. This next revolution is anticipated to arrive with the introduction of 'nanomedicine' which will shift the present medical agenda from one of preventative care to physical enhancement (see section 7.1.3). The thesis determines the significance of medical practice as directly influencing the configuration of hospital space. For example, it was shown that medical exploration is instrumental in creating new medical knowledge. In one instance, new knowledge led to the invention of the stethoscope and thereafter the 'clinical gaze' (see section 5.1.3). This medical revolution required new and additional spaces which ranged from patient examination rooms to complete new teaching hospital facilities. These findings identify medical practice as:

(i) A direct design driver of hospital space

(ii) 'Stage 4' in the process of influencing hospital space (see Figure 4.19:Example2)

(iii) An indicator for future spatial change.

Medical delivery was investigated from 1600 onwards as 100% of events occurred during this period (see Appendix D.11). Furthermore, it emerged that 80% of events occurred after 1800. This strongly identifies an increased activity in changes to medical delivery. The evolution of British hospitals, discussed shortly in section 4.3.1, experienced a similar revolution concurrently. Therefore, a link between medical delivery and hospital space was suggested but it emerged that medical delivery relied strongly on other factors to instigate spatial change. For example, political and social pressure resulted in the *1879 Public Health Act*. The outcome impacted upon delivery when a new ambulance service was introduced. From this new method of transportation, additional accommodation for nurses and drivers was introduced into hospitals throughout the 1880s (see Appendix D.12). Equally, the effect of the *1946 NHS Act* nationalised healthcare delivery but hospital space was not affected until the *1962 Hospital Plan* was introduced. On this basis, the status of medical delivery's relationship with hospital space is:

(i) 'Stage 3' in configuring hospital space (see Figure 4.10: Example 3)

(ii) Not a direct driver of hospital space.

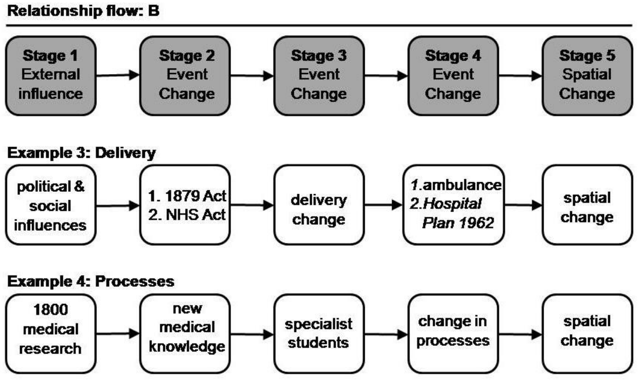


Figure 4.10 Relationship flow diagram B: Analysis of medical delivery and processes.

Statistical data revealed 33.3% of medical process events occurred in both 8.8% and 17% of the analysed timeframe (see Appendix D.13). This quantitative finding is not as significant as two other important issues revealed: (i) the consistent on-going revolution trend between segregated and non-segregated care; (ii) medical processes' close linkage with configuring hospital space. Process, as a design influence, was identified as a step in the later stages of changing hospital space. For example, in the 1800s, new medical knowledge was disseminated amongst medical students who became doctors in numerous specialist areas (see Figure 4.10:Example 4). However, no departmental segregation took place until physicians revoked the status of specialist care within British public hospitals. Once admitted, the spatial outcome of segregation was departmentalisation. This significant event pinpoints the beginning of complex contemporary hospital medical planning. As a result, it was determined that medical processes are:

(i) 'Stage 4' in the process of influencing hospital space

(ii) A direct driver of, and strong indicator to, future hospital spatial change.

A relationship flow diagram was created from all section findings (see Figure 4.11). Medical knowledge and delivery are identified as indirect drivers while medical practice and processes as directly influencing hospital space. Based on a five-stage process of spatial change, the following inter-relationships between medical influences were determined as underpinning a significant medical planning principle:

> *New medical knowledge is a precursor for radical change which, as a result of interconnected relationships, its coming into existence revolutionises the delivery of medical care. Thereafter, changes to delivering care affect medical practice and processes. The latter two medical influences are the design factors that diretly impact on hospital space.*

To contextually place this principle, a new generation of medical knowledge was instigated by Feynman's revolutionary 1959 speech. R&D has since created new medical knowledge and concepts for delivering care through the dissemination of scientific information (Stages 1-3). Three events have occurred in this thesis' five-stage process of spatial change. At present, available information is limited concerning future medical practice and processes (Stage 4). This is a major problem for medical planners who need to plan now for spatial change to allow for, what this thesis believes is, an incoming major spatial revolution (Stage 5).

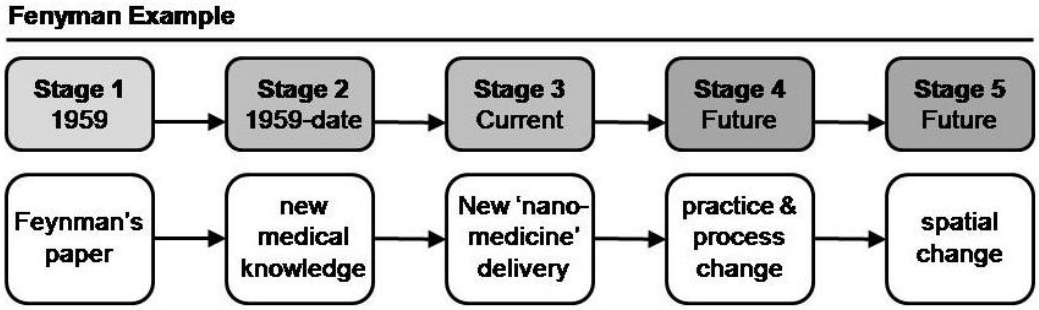


Figure 4.11 Medical influence flow: General and Fenyman scenario/example.

Period of time	No. of events	Total number of events (400BC-date)	% of events
Post-1600(17% of time)	14	21	66.6
Post-1800(8.8% of time)	10	21	47.6

Table 4.5 Table of post-1600 /1800 findings: Number of events and ratios.

	Medical Influence	Driving effects of hospital spatial change	Stages to change
4.2.1	Knowledge	Renaissance to Industrial revolution developments, European institutions, teaching hospitals, 20th century developments.	3
4.2.2	Practice	Major transformation occurs after a change in medical practice.	1
4.2.3	Delivery	Legislation and organisation - introduction of ambulance service & acute services, the NHS, technological change.	2
4.2.4	Processes	Segregated care - Baths of Caracalla, 18th century military design, Hotel Dieu's 'hospital'.	1

Table 4.6 Table of medical influence findings: Driving effects of hospital spatial change.

In conclusion of this medical section, numerous events emerge as instrumental to revolutionising British hospital space. Based upon tabled findings in Appendix D.14-6, a combined analysis of medical design influences is listed in Tables 4.5-6. The activity of medical influences is quantified in Table 4.5 where almost half of events have occurred since 1800. Driving effects of spatial change are listed in Table 4.6 where many have progressed only since 1600. Chapter 5's exploration of medical technology explores why changes have escalated over the last two centuries. Meanwhile, on the basis of section findings, only post-1600 architectural events are considered in the next section.

4.3 Architectural influences: Post-16th century

This section's historical exploration of hospital space is taken from the perspective of architecture as a design factor. Five significant periods concerning post-16th century hospitals trace the development of hospital space to its current and present status.

4.3.1 16th–20th century hospitals: The source of revolutionary hospital designs

This first historical period contains four significant events (see Figure 4.14). These are the architectural milestones leading to the NHS's inauguration.

The first event was the English Reformation which changed the course of hospital space directly by obliterating the continuation of ecclesiastical typologies across the British architectural landscape. Thereafter, public healthcare was transferred to hospitals where medical practice was administered predominantly in antiquated rented townhouses[14]. This second event witnessed many hospitals open in non-customised accommodation. These include the Royal Marsden, Charing Cross Hospital and St. Mary's, Paddington. While adapting to non-clinical spaces, the influx of increased patient numbers directly influenced hospital space by forcing hospitals to move regularly to larger rented

---

[14] Doctors would open a hospital by renting out houses with money donated to their funds.

premises (Barry & Carruthers, 2005:105-123). This finding identifies the absence of British public hospital typologies between the 16th-19th centuries.

Third, although forward thinking existed amongst 18th century military hospital designers, it wasn't until Florence Nightingale published her *Notes on Nursing* (1859) that clinical functionality took precedent in British public hospital design[15] (Nightingale, 1969:12-24). Why this hadn't occurred earlier leans more towards weak financial circumstances and a lack of construction rather than theoretical ignorance. For example, Nightingale, John Roberton and George Godwin all encouraged the use of a pavilion styled typology, particularly upon the 1790s Hotel Dieu, Paris[16] [17] (Richardson, 1998:5-6). The pavilion typology was adopted into UK hospital design once finance became available. Exemplars include the Blackburn Infirmary (1858-65) and St. Thomas', London (1871) (see Figure 4.12). The medical planning of this revolutionary typology was driven conceptually by the 'miasmatic' theory, even though this theory had been medically refuted during the 1840s (Richardson, 1998:3). Nevertheless, Nightingale underpinned St. Thomas' design with miasmatic ideologies, founding its pavilion typology upon a distinct set of architectural principles. These included a response to separation, fresh air and cross ventilation, sunlight, greenery and new nursing methodologies which characteristically respond architecturally to the nature of human well-being (Richardson, 1998:7). As Dr. Nick Black describes of 19th century pavilion typologies:

> New hospitals therefore featured large windows, good ventilation more space for each bed, balconies, separate ward blocks, and sanitary facilities (Black, 2005:1395).

---

[15] Sourced from observations from nursing soldiers during the Crimean war, Nightingale encouraged the hospital environment to contain access to good ventilation, sun and hygiene.

[16] John Roberton, a Manchester surgeon, presented a paper to the Manchester Statistical Society (1856) while George Godwin, editor of the weekly architectural journal *The Builder*, was reknowned for 'extolling the virtues of the Continental pavilion plan' (Richardson, 1998:5-6).

[17] French revolution stopped this hospital from being rebuilt in the late 1790s. Plans were done by Architect Bernard Poyet (1742-1829).

The medical planning of St. Thomas' directly reflected late-19th century medical practice and delivery. The design consisted mainly of ward areas now known as Nightingale Wards. Spatially, each ward consisted of a large open space with 15 beds on either side that overlooked exterior gardens in response to what Nightingale referred to as 'patient fancies'. The design allowed for cross-flow ventilation and good visibility between staff and patients. Nightingale's architectural intent was to bring 'variety of form and brilliancy of colour in the objects presented to patients' (Nightingale, 1969:59). This hospital design model became a dominant template for British sanatoriums, until the mid-20th century when healthcare evolved radically as well as rapidly (see Appendix D.17).

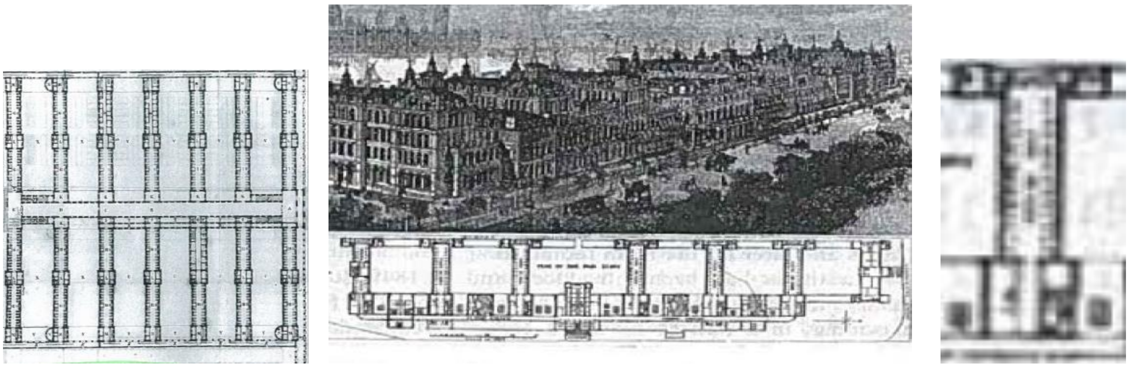


Figure 4.12 Left: Plan of Hotel Dieu, 1790s (Richardson, 1998:6). **Centre/Right:** Perspective and ward plans of St.Thomas', 1871 (Barry & Carruthers, 2005:43).

Medical planning arrangements are recorded as being basic for the few 19th century British hospitals.

> Internal arrangements of hospitals were subject to periodic alterations, the uses of rooms changing as demands on hospital accommodation varied....the ward, had no strict form or size until the second half of the 19th century, as opinion shifted between a preference for them to be large or small...there was a need for other patient areas, such as operating theatres, as well as administrative offices and staff accommodation (Richardson, 1998:4).

Historian Harriet Richardson's account of 19th century hospital space arrangements is significantly crucial to this thesis. While not classified as an event or revolution, evidence pinpoints a stage when, over a century ago, hospitals practised spatial flexibility in accordance with functional demand. This is the ultimate goal for present hospital medical planning solutions. The parameters that have led to recent spatial complexities are discussed shortly to inform designers of the core principles needed for designing future flexibility.

Legislation passed	Government type	Legislation description	Architectural responses to legislation
1866 Sanitation Act	Conservative	Local health boards became responsible for clean water	All new buildings to have closed water closets
1853 Compulsory Vaccination Act	Conservative	All citizens to be vaccinated against smallpox	Reduced clinical area for treating smallpox
1875 Public Health Acts	Conservative	Running water and internal sewers	New hospital annexes
1897 Public Health Act	Conservative	New ambulances transferred contagious patients to hospital	Added area near to clinical admissions

Table 4.7 Thesis architectural analyses of Public Health Acts (1850-1900).

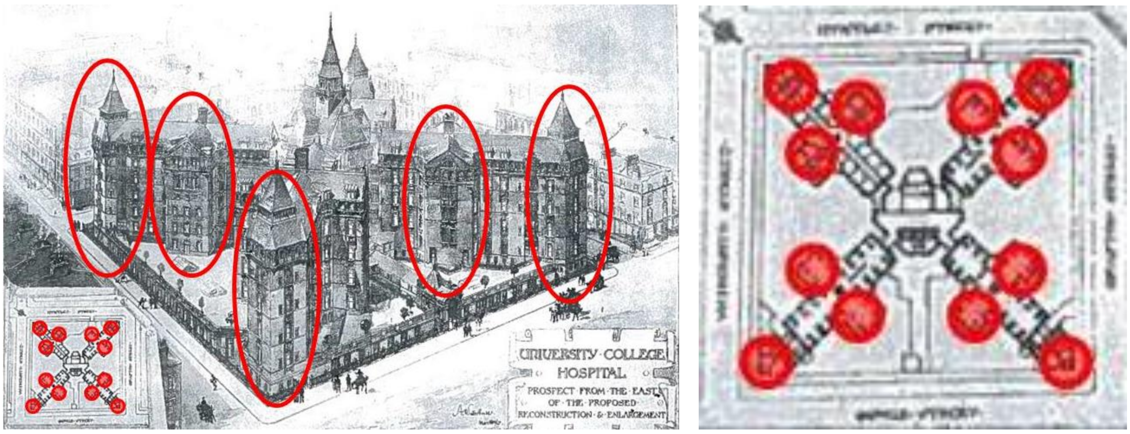


Figure 4.13 Analysis of spatial influences: Introduction of piped water on typology design, perspective and plan of UCLH (highlighted in red).

The fourth event is a conflation of architectural developments. One influence involves government legislation delivered in the form of public healthcare acts. For example, the outcome of the *1866 Sanitation Act* influenced hospital space directly by introducing water closets (WCs) into hospital buildings. Other legislative examples, listed in Table 4.7 and Appendix D.18-9, highlight the implications of their outcomes upon the evolution of hospital space. Another post-1850s architectural development emerged in the form of new construction methods. In the 1880s, installed piped water introduced washrooms into hospitals for the first time. All wet areas were located to the exterior of buildings from an inability to run piped services internally. This coincided with new knowledge concerning infection control, such as, the practice of hand-washing. The outcome formed annexes to hospital typologies which distinguish this short period of hospital design distinctly until architectural services were revolutionised and became internalised in the 1900s (see Figure 4.13).

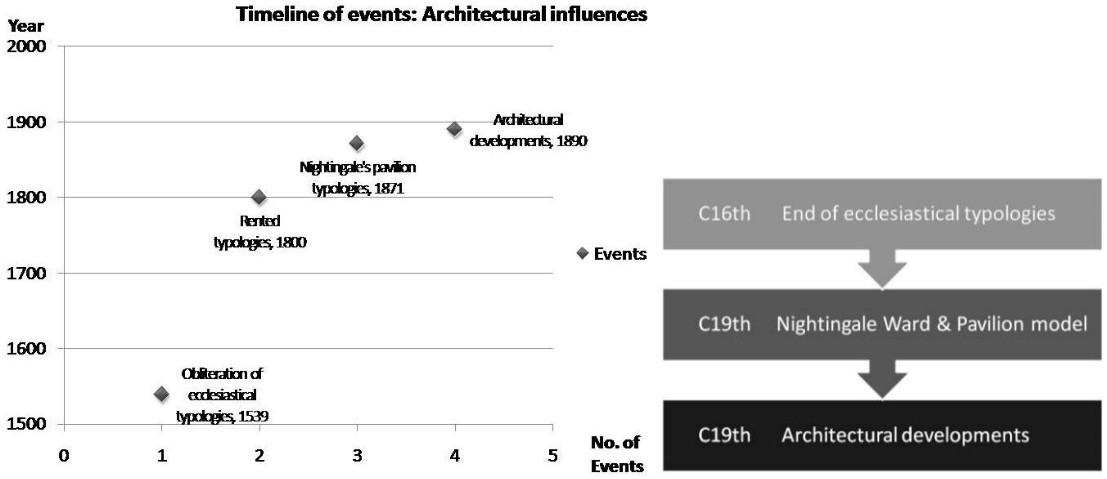


Figure 4.14 Architectural findings: List of events and revolutions (C16th-20th).

While these events are considered minor in comparison to 20th century developments, 16th-20th century architectural events significantly identify that:

(i) Pre-NHS hospitals were predominantly pavilion styled typologies

(ii) Medical theology and planning were beginning to revolutionise hospital design

(iii) Emerging architectural technologies were impacting upon design

(iv) The Nightingale Ward/pavilion typology is the second spatial revolution in medical planning history after the Baths of Caracalla (see Appendix D.6).

4.3.2 Early-20th century hospitals

The 20th century is by far the most active of all eras from a historical perspective of hospital space. This section unravels early-20th century architectural revolutions.

(i) 1900-1950: Modern era of hospital design

Early-20th century hospital design was ‘driven by a handful of European sanatoria’ based on palliative care remaining dominant, as discussed in Chapter 2’s examination of Paimio’s sanatorium (Willis, 2002:46). Derived from the pavilion typology, the thesis considers the sanatorium typology model to be the third revolution in British medical planning history (see Appendix D.20). However, while effective for their time, veranda styled solutions became inappropriate for delivering 20th century healthcare quickly. Revolutions in bacteriology and pharmacology resulted in contagious diseases no longer prevailing that resulted in population growth and mass urban development which pressurised hospital resources and space immensely (Watkin, 1978:4-11). Infection control became precedent whereby physicians disregarded the necessity for pavilion typologies (Hughes, 2000:24-9). By 1940, enormous pavilion footprints had become spatially inefficient and operationally uneconomical. Affordable efficient hospital design became prominent in the face of soaring financial costs (Wagenaar, 2006:31-2). Spatial problems were aggravated further by the then expansion of urban fabrics where most large hospitals had been located normally. Land costs escalated as demand for available urban space intensified. Hospital designers were forced to revisit hospital medical planning models. Research into theoretical concepts was intent on achieving affordable hospital design solutions. Theories, still relevant today, included economies of scale, core v flexible space as well as long life v adaptable hospital design strategies. The outcome of research resulted in new design elements which included double loaded corridors, alternative bed numbers and private spaces, of which, all were supported by new lift technology that reduced travel distances.

The continued division of medical functionality resulted in the emergence of new specialist departments which included Radiography and A&E. By the 1940s, palliative care was replaced by a high-tech surgical practice supported by new medical technologies discussed in section 5.2. In response to an ever evolving medical practice, a new medical planning formula was created which ‘to the great credit of those involved in the design-construction process, the major needs to this type of accommodation’ were met between 1945-1970 (Thompson, 1983:69).

Simultaneously, an architectural revolution emerged with novel and modern forms that filtered through to hospital design to replace the sanatorium typology. Through improved construction methods of mass produced steel and glass, the institutionalised authority of the medical profession was embedded in monolithic mega hospital forms (Richardson, 1998:11; Miller & Swensson, 2002:39). Medical professionalism and efficiency was embodied in the creation of new high-rise tower hospitals through off-site manufacturing and rapid on-site assembly (Monk, 2004:10). This ‘matchbox-on-a-muffin’ typology consists conceptually of a vertical ward block on top of horizontal podium of D&T departments (see Figure 4.20). Examples of this medical planning model include the Royal Free, Guy’s and Charing Cross hospitals (New London Architecture, 2005:61). The ‘matchbox-on-a-muffin’ typology is identified as the fourth medical planning revolution in medical planning history. A multitude of varieties, including the K type (Diaconessenhuis Hospital, Netherlands, 1965), deviated from this new vertical model. Derivatives are detailed in Cor Wagenaar’s *The Architecture of Hospitals* but one variation is of interest here. Ironically, the T model, is typified by Le Corbusier’s Ospedale Civile. This typology is categorised as a ‘matchbox-on-a-muffin’ typology based on its medical planning arrangement rather than its architectural form (see section 2.1.3).

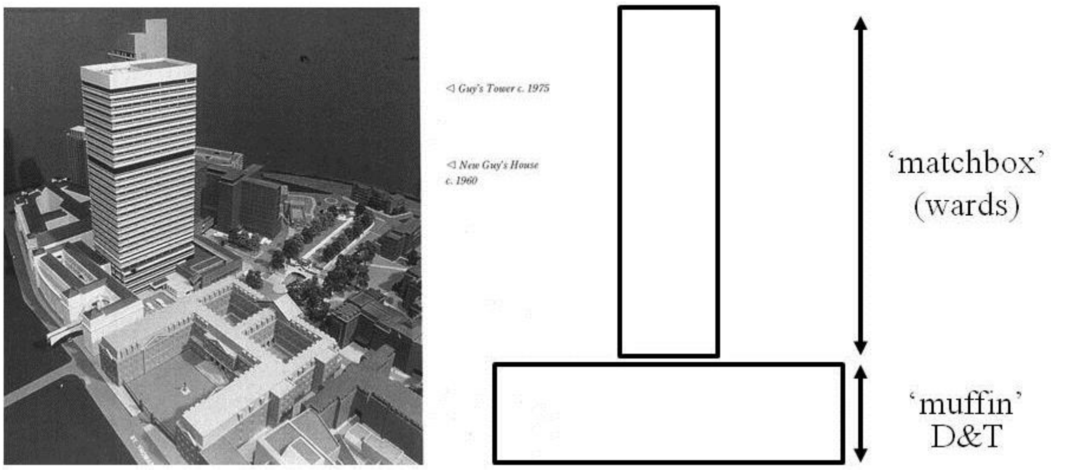


Figure 4.15 Left: 'Matchbox-on-a-muffin' typology, Guy's Hospital, London (James & Noakes, 1994:71). **Right:** Author's conceptual sketch.

Post-1910 developments in architectural services were responsible equally for revolutionising hospital design. The necessity for sanitary annexes was eliminated as piped water became embedded internally (Richardson, 1998:11). Other service improvements include the invention of mechanical air conditioning, ventilation and fluorescent lighting (Nield, 2003:14). The outcome created a 'deep-space planning' model which was inspired by American multi-storeyed hospitals (Richardson, 1998:37). This fifth medical planning revolution consisted of a compact medical planning model that altered the principles of hospital design profoundly by centralising services to minimise long corridors. As Richardson described, 'wards and services were more fully integrated into one vertical building' (Richardson, 1998:37). To create this huge leap in medical planning, access to daylight and external environments became eliminated as clinical functionality became superior to human experience. Negative repercussions were experienced as functionalism was designed to its very utmost. The quality of architecture and wellbeing of its human occupants were affected disastrously (Ulrich, 1984:420-1). Many 20th century hospitals were formed upon the 'deep-spaced plan' model. Contemporary hospital design encourages a shift away from this formula to reach, as Aalto argues, a human approach to design.

(ii) Technology's influence on hospitals

20th century technology progression bypassed all previous periods' achievements. New construction and engineering methods allowed for innovative architectural forms. Novel materials assisted with developing new clinical environments. Similarly, healthcare experienced numerous technology revolutions during this century. With simultaneous evolutions in medical technology and hospital medical planning, the thesis raises the possibility of deeply embedded inter-connections. Chapter 5 explores this relationship to confirm technology's role in influencing the configuration of hospital space.

(iii) NHS hospitals: Inherited estates

Stated in the Hospital Surveys report (Ministry of Health (MOH), 1941), 20th century hospitals had not kept pace with medical and demographic changes (Willcocks, 1967:22). Watkin describes the NHS as:

> 2,800 hospitals…vested in the minister on 5 July 1948, 45 per cent were originally built before 1891 and 21 per cent before 1861 (Watkin, 1978:56).

Therefore, the status of medical functionality within NHS hospitals in 1948 consisted of 21% of hospitals functioning in century-old non-customised buildings. More than half needed complete renovations for new technologies, plumbing as well as heating. During the 20 year period prior the *1962 Hospital Plan*, the solution for new technologies was the *'make-do & mend'* refurbishment programme (Noakes, 1982:118). However, the deterioration of spatial problems proliferated after the NHS's inauguration, when specialists' hospitals amalgamated with general hospitals to gain access to expensive medical equipment (Barry & Carruthers, 2005:184-5). The spatial organisation of medical practice became fortified by territorial specialist consultants[18]. The outcome increased departmental numbers adding to the complexity of medical planning. This

---

[18] Introduced authority over the continual existence of their 'own' hospitals which, in continuing today, causes many spatial design problems.

critical event maps when NHS hospitals became intricately divided but spatial representation was not palpable until new NHS hospitals were built in the 1960s.

One spatial event took place in response to the *1939 EMS Act*. During WWII, over 50,000 temporary beds in prefabs were constructed on existing hospital sites (Richardson, 1998:41). Many became permanent fixtures. Some still functioned until recently in atrocious conditions (Pembury Hospital, Kent, 2007). By 1956, the state of NHS hospitals was established in a *Committee of Enquiry* report. Its chairman, Claude Guillebaud, concluded wisely:

> More money was needed to build new hospitals, as the profession was trying to practise 20th-century medicine in 19th-century buildings (Barry & Carruthers, 2005:370).

Eventually, finance was arranged to reconstruct hospitals through the *1962 Hospital Plan* but hopefully is not a repeated situation for future 21st century hospitals.

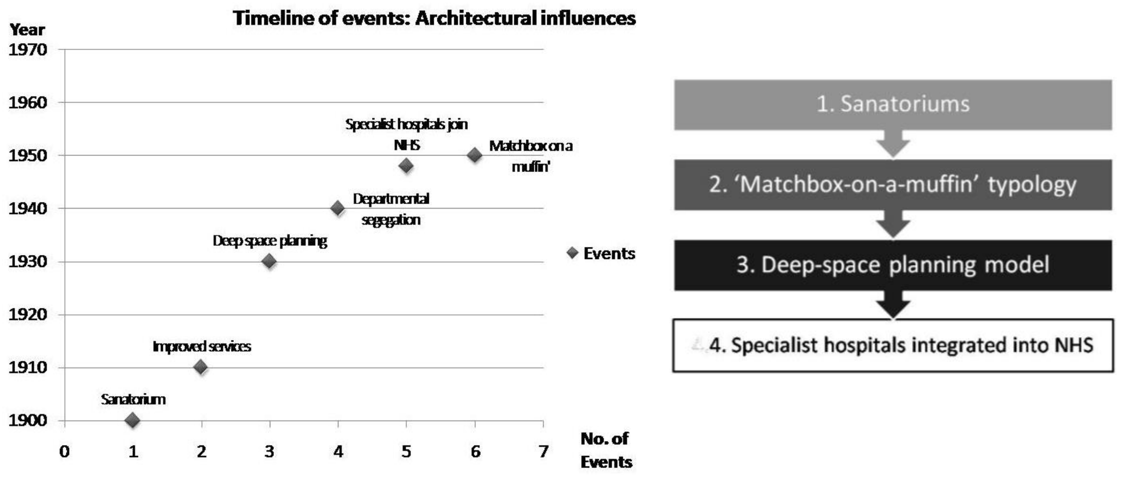


Figure 4.16 Architectural findings: Early-20th century events and revolutions.

In summarising early-20th century hospital design, six events and four revolutions were recorded during this very short historical era (2%) (see Figure 4.16). From changes in architectural form to the growth in medical planning complexities, these spatial events laid the foundations for late-20th century medical planning evolutions.

4.3.3 British Hospital Design Research (HDR)

Prior the 1960s, where few NHS hospitals were built, theoretical exploration took precedence to hospital construction. Founded upon American design research, numerous groups are accredited with developing post-WWII British hospital design models. These include LD architects, Medical Architecture Research Unit (MARU), Nuffield Trust and the Hospital Buildings Division (HBD) at the MOH (Monk, 2004:10). These scholars were responsible for studying topical HDR subjects, such as, the effects of high v low rise buildings, racetrack v peripheral wards, interstitial service floors and automated supply systems (Francis et. al., 1999:7). As a result, HDR influenced the creation of British hospital design criterion and medical planning models employed between 1960-2000. Numerous hospital prototypes were constructed to test HDR principles. For example, findings from research conducted upon OPD and A&E departments at the Walton Hospital, Liverpool (1961) were incorporated into the NHS's Greenwich Hospital design in 1969 (Noakes, 1982:119). The extent of British HDR can only be mentioned here but research outside of this study is recommended (see Table 4.8).

1. *Studies in the function and design of hospitals* (Bristol University/Nuffield Trust, 1955)

2. Nuffield Ward model (see Appendix D.21).

3. Creation of HBN documentation (MOH, 1961).

4. 'Hospital Street' (Weeks at LD architects)

Table 4.8 List of revolutionary British HDR events.

In Chapter 2, Weeks and Le Corbusier were identified as hospital design researchers. At the MOH, HDR was being conducted specifically for NHS hospitals. Under Enoch Powell's *1962 Hospital Plan*[19], 233 new and upgraded NHS hospitals were proposed but 'without any previous experience of such a novel task' budgets were miscalculated

---

[19] In *The 1962 Hospital Plan for England and Wales*, £500M was allocated for the building and modernisation of 90 new hospitals by 1971 (Watkin, 1978:60).

completely (Francis et. al., 1999:29). As a result, Powell's hospital building programme was halted while a cost-reducing design solution was found. The MOH sought inspiration from two precedents; the works of Gordon Friesen and Powell & Moya architects.

Friesen's noted 'Automated Hospital' rationalised hospital functionality conceptually. He proposed:

> In an age of mechanization, logic dictates that some of the production methods of industry should be applied to certain areas of the hospital (Friesen, 1961:7-9).

Searching for cost-effective solutions, MOH architects observed the following of Friesen's principles:

> Removing the maximum number of functions from the ward to remote, centralized departments where their work could be easily surveyed, controlled and rendered more efficient (Hughes, 2000:39).

Alternatively, Powell & Moya architects offered theoretical innovation where three of their hospital projects - Swindon (1959), Wexham Park (1966) and High Wycombe (1966) - represent some of the NHS's first 'matchbox-on-a-muffin' type typologies (see Appendix D.22-4). At Swindon, 'this pioneering hospital set the standard...for the expansion of the health care building programme' while Wexham Park was conceptually controversial with its radical version of the 'matchbox-on-a-muffin' typology (Monk, 2004:55). Wexham's unique philosophy was formed upon the principle that functionality including wards were 'all on one level, no stairs, no ramps, no lifts' (Powell, 1966:123). Therefore, Wexham's medical planning strategy locates all accommodation at ground-floor; theoretically quickening travel distances and creating flexibility for future expansion (Hughes, 2000:41). Additionally, Powell & Moya incorporated Weeks' 'hospital street' concept where the hospital's communications spine linked all departments together (Smyth et. al., 2006:4). However, Wexham's horizontal site-specific typology was not easily transferable upon which an alternative medical planning solution had to be created for High Wycombe’s restrictive urban site. Here, the medical planning strategy divided the building into three zones. Conceptually, the strategic medical planning areas were: Wards; D&T; services.

Collectively, these precedents offered the MOH a variety of conceptual solutions which assisted with the production of a new MOH hospital design model. Based upon HBN documentation, this *PGH600* typology consisted of a central core of departments surrounded by peripheral wards. This model was first realised at the Greenwich DGH in 1969 (Smyth et. al., 2006:3). This 800 bed urban hospital of low-rise rectilinear form was pierced with courtyards to allow daylight within deep-space planning areas. The MOH’s utilisation of space revolutionised medical planning at the time by minimizing travel distances associated with hospital running costs. For example, Greenwich’s OTs, ICU and surgical beds were all located adjacent on the same floor which was a revolutionary approach to strategic medical planning for its time (James & Noakes, 1994:18). The Greenwich DGH was equally revolutionary regarding its services component which was heavily influenced by Friesen’s Automated Hospital:

> The new NHS hospital was not just to be modern, but more meritocratic, mechanized and efficient (Hughes, 2000:41).

The MOH introduced a ‘universal space’ of ‘interstitial spaces’ between each floor where internal services could be accessed flexibly without disturbing clinical functionality. This concept continued to be developed by the MOH for many years. These features represent post-WII NHS medical planning concepts (Spring, 1979:55).

Each identified HDR event was found to be revolutionary (see Figure 4.17-8). Hence, this study emphasises the significance of ongoing HDR within medical planning practice.

EVENTS **FLOW OF EVENTS**

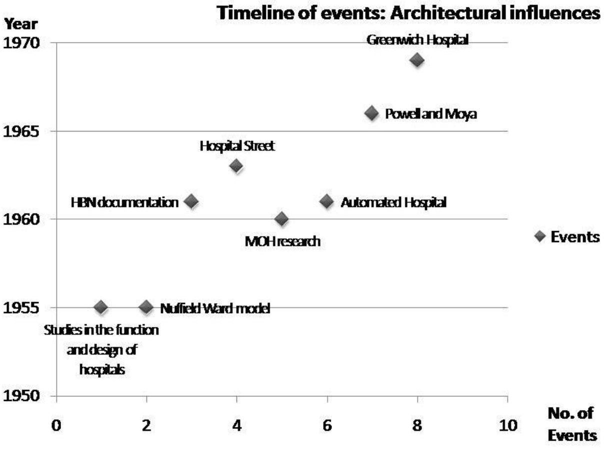


Figure 4.17 HDR findings: List of events.

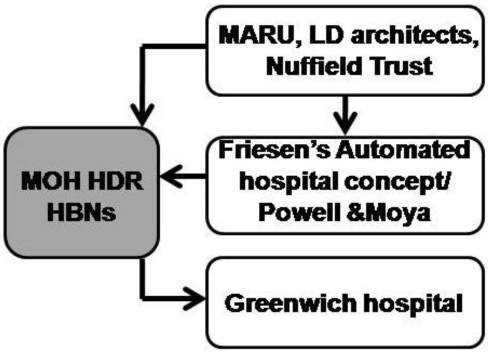


Figure 4.18 Analysis of relationships: 20th century HDR events.

4.3.4 Typological outcomes of British HDR (1960s-2000)

1970s hospital design was driven by numerous HDR. Topics included cost efficiencies, low energy buildings, indeterminate architecture and 1960s mega hospitals. Additionally, 1980-90s hospitals were influenced by post-modernist, high-tech design where the atrium became a new prominent feature in the form and organisation of hospitals. 'Design and build' (D&B) competitions introduced a new cost effective delivery methodology in response to what had become high-tech, expensive hospital buildings (Monk, 2004:13). From this background, three generations of hospital typologies were produced from MOH HDR - now renamed the Department of Health and Social Services (DHSS). Each typology is an evolution of the former and chronologically known as: Best-Buy, Harness and Nucleus models. Their concepts and outcomes are outlined to expose the positives and weaknesses associated with late-20th century NHS medical planning strategies. This knowledge is critical to understanding the context surrounding why so many NHS hospitals needed replacing by 2000.

(i) Best-Buy Typology (1960s-70s)

The *Bonham Carter Report*[20] (1969) proposed the need for additional NHS hospital beds. The DHSS argued against this policy advocating the necessity for alternative solutions to avoid financial crises. Policies that would 'shorten length of stay, increase throughput and reduce established ratios of beds per 1,000 population' greatly interested the DHSS (Moss, 1978:12). This proposal was driven by 1960s hospitals which had 'left a sickening legacy of high building costs' (Spring, 1979:54). For example, Northwick Park was a revolutionary model but its delivery was managed inadequately. Subsequently, Weeks' model was classified as economically and spatially expensive at the time. Therefore, the DHSS took inspiration from their own Greenwich DGH for the creation of a Best-Buy hospital model (Francis et. al., 1999:30). A *Mark I* model was designed consciously as a two-three storey building to allow for a low-energy strategy that utilised natural light and ventilation. This model contrasted greatly with the then popular vertical hospital typology by centralising all departments to either side of 'the hospital street' with peripheral wards surrounding (Smyth et. al., 2006:3).

Of interest to this study are two medical planning principles underpinning the Best-Buy typology. The first driver was the minimisation of cost which was approached by a twofold briefing strategy: (i) reduced SOA; (ii) universal usage of briefed hospital spaces.

> Best-Buy hospitals provide a dramatic example of increased space utilisation with a resultant saving in space provision (Moss, 1978:11).

This utilisation theory was novel for NHS hospital design. For the first time, clinicians' spatial territory was challenged against usability and occupancy rates. Unfortunately, this concept was overextended and weakened by reduced SOA areas. Functionality

---

[20] The *Bonham Carter Report* (1969) stated that more hospital beds were needed. In 1971, the DOH advised the government against this policy and not to create anymore beds for reasons of cost implications. While the new government wanted larger hospitals, projects were already on site and therefore could not be changed (Watkin, 1978:66-8).

became impossible, which resulted in a spatially more generous *Mark II* design model (Watkin, 1978:66). Costs were rationalised further by a unique services supply strategy. The design introduced 'an intermediate level, with ramps up and down to the two hospital floors' to shorten staff travel distances (Noakes, 1982:123). The second driver was a standardisation policy introduced to reduce costs. A strategy of 'simple construction methods' was flawed as it was incompatible with existing hospital buildings which was weakened further by the model's suitability for open flat sites only (Francis et. al., 1999:31). This restricted the Best-Buy typology's transferability onto dense urban sites. This fault was never addressed fully as only two Best-Buy hospitals were completed at Frimley and Bury St. Edmunds[21] (1974) (see Appendix D.25-7). Both hospitals were designed identically and delivered through standardised fast-track building programmes on green open sites in a bid to decrease design and construction costs (Millman, 2009). Unfortunately, 1960s HDR had not anticipated for the mid-1970's radical escalation in capital costs. The Best-Buy solution was deemed unaffordable forcing the DHSS to revisit their hospital design model.

(ii) Harness typology (1970s)

A systems approach HDR was adopted to develop the NHS's Harness typology. This was a more flexible and economical option from the previous Best-Buy model. The Harness typology consisted of:

> A synthesis of the best current ideas in hospital policies, planning, building technology, environmental services design and dimensional co-ordination (Francis et. al., 1999:34).

The Harness's medical planning strategy is strictly based upon a 15.6 meters (m) grid of horizontal deep-space planning arrangement with a 4.5m floor to ceiling height. The building was minimised to four storeys in height where all services were uniformly

---

[21] Bury St Edmunds included the use of electric tugs, wide corridors, ramps and standard treatment rooms.

located along the main circulation or ‘harness zone’. From here, all departments linked together with gardens in-between for access to natural daylight (Francis et. al., 1999:34). The Harness also included the first sterilisation and Ear, Nose and Throat (ENT) units which map another historical medical planning development. Two principles directed this typology, of which, both are important to this study’s concerns.

The first principle was flexibility through standardisation which was introduced in response to the Best-Buy’s failed solution. However, architectural delivery was not executed to the achievements of Aalto’s Paimio Sanatorium. Standardisation was incorporated through a variety of DHSS systems[22] and only based ‘at department level’ which allowed for architectural adaptability and variety of exterior form (Francis et. al., 1999:31-3; Pearce, 1978:18). The second and foremost principle was that the Harness model was to be economically efficient. Savings were not achieved in the light of a prosperous economic era. Lessons learnt from Best-Buy spatial reductions redirected areas to be enlarged considerably. Unsurprisingly, the outcome increased both capital and running costs but the scheme’s full height ramp did result in the building being completed several months before schedule. This financial success was a feature delivered through medical planning design (Noakes, 1982:126).

The Harness model existed during a short lived economic boom which lasted until the 1973 oil crisis. The number of Harness projects was slashed from seventy to two which include Southlands and East Birmingham hospitals (see Appendix D.28). Action to reduce building scopes was tested through a smaller version of the Harness model but finance was still unavailable to deliver a nationwide rebuilding programme. Meanwhile, inflation soared increasingly which resulted in poor architectural finishes and high

---

[22] DHSS systems included CUBITH, ADB and others (Francis et. al., 1999:31-3).

maintenance bills for both Harness projects. More HDR was conducted by the DHSS to address ongoing NHS financial shortages.

(iii) Nucleus (1970s–90s)

With the NHS's reorganisation (1974-5) and hospital rebuilding programme on hold, minister Lord David Owen (1974-7) was appointed to tackle the arduous task of rebuilding Britain's DGHs (Watkin, 1978:58-70). Driven by an unconventional perspective, that sought the 'best use of the space permitted', the reconstruction of NHS estates progressed forward with the DHSS's latest Nucleus model (Francis et. al., 1999:38). The delivery of desperately needed hospitals became a reality between 1981 and 1990. Approximately 130 Nucleus schemes across Britain were realised. 'Smaller than the mega-hospitals of the 60s', the Nucleus hospital was designed to respond to growth and change (Christopher, 1982:14). Commencing as a 300-bed solution, the template was capable of expanding to a 600 or 900 bed facility in staggered stages of development (see Figure 4.19-20). Conceptually, this hybrid model is a horizontal typology formed of a 'hospital street'. Standard departments branch out in 15.6m squares of buildings and courtyards (Noakes, 1982:128). This deep-space planning model consisted of integrated services and racetrack wards and was established upon three similar driving principles as previous DHSS models. A detailed exploration of each area is beyond this study's limits. Here, the significance is to identify the principle factors underpinning recent NHS hospital space invalidity.

The first principle was the NHS's approach to standardisation which included standardised systems, such as, HBN guidance. Taking on board lessons-learnt from the failings of the Harness typology, the DHSS was warned not to standardise the Nucleus model too rigidly. Consequently, no standards were imposed for the design of building structures or external cladding systems (Pearce, 1978:19).

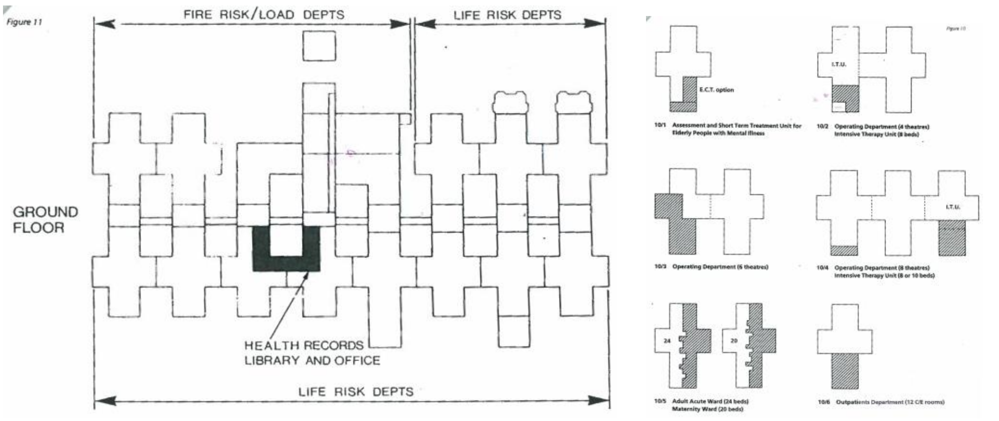


Figure 4.19 Left: Nucleus Model 2: Departmental location for Health Records and Office Accommodation. **Right:** Description of notional design solutions (DOH, 1992).

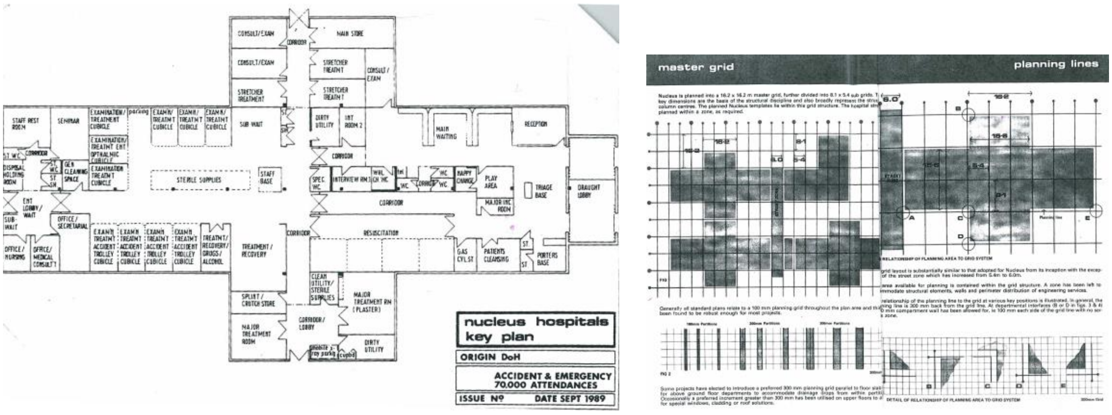


Figure 4.20 Example of DOH Nucleus study packs (1992).

The second principle was the ever-increasing pressure for the economisation of hospital buildings. The brief given to the DHSS was explicit; ‘buildings were to be cheap to build and run’ (Pearce, 1978:19).

> Low-cost small-phase designs were wanted, ‘Best buy’ cost £10m and was inflexible of plan; Harness was too big and costly. But both projects offered data for new designs (Pearce, 1978:18).

In response to stringent demands, a Nucleus model was produced to provide a cheaper option than a Harness typology (Building Design, 1979:6). The Nucleus design focused on low energy policies with the best example was represented at St. Mary’s Hospital, Isle of Wight (IOW) (see Appendix D.29). 50% of their energy running costs were reduced from the outcome of HDR. A second area of savings was produced by employing a D&B process. This was achieved by reducing programme times throughout a whole project's design and delivery process (Monk, 2004:13).

The third factor was the approach to spatial reduction which dominated hospital design for over twenty years. From a medical planners' perspective, this approach was critical to the spatial failure of Nucleus hospitals. Initially all spaces were 'pared down to 20 per cent below' HBN guidance (Pearce, 1978:19). This flawed strategy caused drastic repercussions for clinical functionality within all Nucleus hospitals. This spatial policy was weakened by a novel methodology that reduced space 'by planning all departments to fit within the standard template' for £6 million per department (Francis et. al., 1999:36). The outcome created a rigid template that standardised all departments into a cruciform shape of 1,000-1,100sqm approximately (Monk, 2004:12). Plans, elevations and engineering grids were created from NHS data packs where grid dimensions for a Nucleus template were fixed: 16.2 meters (m) x 16.2m; sub grid of 8.1m x 5.4m. Tested and established to comply with the size of a fire compartment, these measurements also catered for natural daylight and critical dimensions for certain high-tech rooms at that time (Francis et. al., 1999:37). Additionally:

> The length of the cruciform is deliberately the length of an old standard Nightingale ward so that Nucleus units can be fitted piecemeal into hospitals whose old wards are gradually demolished (Christopher, 1982:14).

When combined these templates created a further spatial reduction as 'the horizontal linking up to self-contained compartments is designed to require minimum movement' of staff and goods throughout the hospital (Pearce, 1978:19).

The Nucleus typology achieved its then financial goal but its success was unsustainable. No long-term spatial solutions or strategies to maintain cheap building materiality were incorporated. This study identifies these approaches as central to the failure of the

Nucleus model and reinforces the importance of flexible design solutions for hospitals. Three important trends identify why so many Nucleus hospitals needed rebuilding after such a short interval:

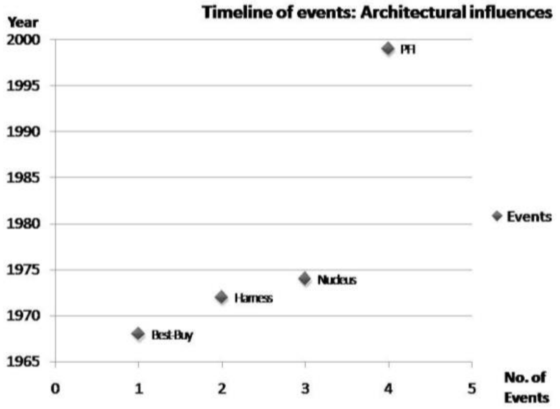
(i) Inappropriate adoption of standardisation in medical planning creates rigid and inflexible hospitals

(ii) Spatial reduction compromises functionality

(iii) Employment of cheap, low-grade materials is economically unsustainable.

The thesis recognises these trends as critical medical planning lessons.

EVENTS



FLOW OF EVENTS

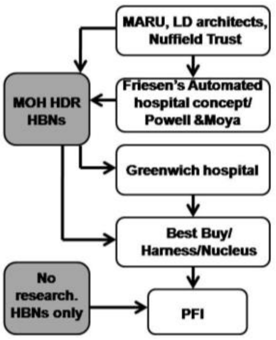


Figure 4.21 Analysis of findings: British HDR events.

Figure 4.22 Diagram of analysed HDR outcomes.

To summarise, the innovativeness of DHSS prototypes would not have been achieved without essential HDR (see Figure 4.21-2). Concepts of flexibility, economies of scale and standardisation were all critical design factors included in late-20th century NHS hospital design. In general, Nucleus hospitals were the most significant with regards to the legacy of hospitals that PFI replaced. However, the attributes from all DHSS models are of beneficial use to future medical planning solutions.

4.3.5 Post 1990s: PFI

Social healthcare had developed into an expensive high-tech service by the 1990s. In a desperate bid to raise equity, strategies to resolve the situation included the sale of NHS estates and the regrettable dismantlement of the DHSS's HDR unit (Francis et. al., 1999:9). By 1997, 50% of NHS estates were recorded as pre-dating 1948. In response, a new capital investment programme (*Hospital Plan 2000*) was put in place to rectify the issue. By 2008, £29 billion had been spent on new PFI NHS hospital construction (DOH, 2007:1-3). In the face of financial efficiency, the government adopted a 'larger but fewer acute hospitals' building strategy which was driven by:

> Staffing issues (reduced working hours, new training needs, explicit job descriptions, etc), a reduced need for beds, and a belief in economies of scale (Black, 2005:1396).

As a result, a new wave of hospitals emerged with the first mega PFI hospital completed at the Norfolk & Norwich Hospital (1999). However, while the opportunity for a new hospital design model was available, this event did not appear for the following reason.

> In the NHS there is no coherent research agenda or programme of research studies at present. This confirms a substantial break in what was an established approach (Francis et. al., 1999:25).

As a result, the PFI programme was undertaken without appropriate HDR. Consequently, early PFI hospitals were designed to 20th century paradigms of which many replicated the Nucleus model. Hence, experts' concern for PFI hospitals are sourced upon the reusing of a hospital design model that ultimately failed spatially.

In contrast to the DHSS's standardised design models, the medical planning of later PFI hospitals consists of an eclectic array of models designed by multiple private architectural practices. For example, the Nucleus type solution was incorporated at Oxford Radcliffe (2006) and Norfolk & Norwich (1999) hospitals while the 'matchbox-on-a-muffin' type typology was employed at UCLH (2006) and Pembury Acute (2010) hospitals (see Appendix D.30-3). Internally, medical planning has responded to a plethora of new healthcare developments created through high-tech medicine, such as, PET/MRI imaging and keyhole surgery. Collectively, new technologies and associated services have been delivered through improved IT, digital media and locally used computers that transformed the administration of complex acute healthcare. For example, the reduction in patient overnight stays (POS) is linked directly to the growth in minimal invasive techniques. In fact, since the 1990s, day cases have accounted for 80% of operations (Black, 2005:1395). These medical changes have altered the proportion of hospital briefed areas which, in turn, have driven the variety in creating hospital forms. Contextually, NHS hospital design is driven by numerous design factors. Four examples typify the influences pertaining to PFI NHS hospital design.

The first factor is consistently central to the construction of all new hospital buildings. This influence is the availability of capital investment to deliver expensive public healthcare facilities. The post-1990 situation was resolved through a PFI solution, as a new national hospital-rebuilding programme could not have been undertaken without an alternative source of investment. Consisting of private sector companies, where consortia had access to substantial financing, the PFI process established contractors as the regulators of standardising architectural quality. Many faults and negative repercussions have resulted from aggressive financial decisions. These include the use of poor quality finishes, similarly incorporated in Nucleus hospitals, to maximise profits. From my perspective as a medical planner, the main concern is the strict adherence to HBN room areas. Consortia have focused on spatial minimisation instead of long-term medical planning benefits.

Second, the PFI system of FM has restructured hospital functionality. This includes ‘nursing, cleaning, portering, supplies, catering, and maintenance’ (Black, 2005:1395). Due to staff reorganisation, the complexity of transferring goods has increased in PFI hospitals which adds extra flows to an already busy management operation and hospital building. This modification to FM not only alters medical planning strategies. It increasingly adds area to hospital buildings in a sporadic and costly manner. For example, the use of automated guided vehicle (AGV) technology for portering goods across hospitals requires extra space for movement and storage in clinical areas where cost per sqm is greater.

The third influence is British healthcare policy that continues to focus on reducing NHS bed numbers but an additional patient-focused policy has become central to NHS delivery. Currently, the DOH aspires to 50-100% single en-suite bedrooms in all wards.

> However, this falls short of the 2002 review's recommendation that 75 per cent of beds in new hospitals should be in single en-suite rooms (Wanless, 2007:117).

Historically, the architectural composition of wards has been a dominant typology driver. Recently, the design of wards has had to evolve in response to DOH legislation. Shape, size and configuration of bedrooms is no longer standardised architecturally which has offered opportunities for architectural differentiation amongst PFI hospital buildings. However, this beneficial change came with medical planning difficulties, such as, the inconsistency of grid structures between floors. The outcome drives major planning difficulties particularly in lower high-tech floors.

The fourth influence is infection control which has regained its prominence as a hospital design driver. This influence is driven by the rise in nosocomical deaths which became a major NHS problem. Currently, every opportunity is taken to design out medical errors and environmentally induced illnesses, particularly in configuring the 1:50 layout of single patient bedrooms. The clinical effects of 'infection-control' design have been the focus of much recent British HDR based upon American EBD which evolved from the works of Roger Ulrich (Ulrich, 1984: 420-1). While not a focus of this study, in-patient design research is evolving NHS hospital space. As previously alluded, complexities are being added to the medical planning of hospitals as ward designs change.

By 2010, the *Hospital Plan 2000* was nearing completion but the products of PFI are looked upon with disfavour.

> The Future Healthcare Network expressed concern that hospital design is following current healthcare demands too closely and not allowing any flexibility. The life cycle of the current model of healthcare supplied by PFI hospitals is estimated at about five years, while the average life span of the hospitals themselves is about 30 years (Gates, 2005:7).

On this basis, the thesis predicts PFI hospitals will not fulfil their contracted term functionally. How they will cope with future developments should be the focus of POE and new HDR. To summarise, the thesis identifies PFI hospitals as:

(i) Area driven hospitals, too restrictive for future flexible spatial planning

(ii) A missed opportunity to create a 21st century medical planning model

(iii) Possibly unsustainable as non-durable materials may have been procured.

These findings inform the existing status of NHS hospital space.

4.3.6 Analysis of architectural influences

In addition to mapping the development of post-16th century hospitals, four key issues are responsible for the current state of NHS hospital space.

First, finance dominates as an external driver of hospital design consistently. This influence impacts on two levels: the number and size of hospitals; the quality of buildings themselves. This was strongly identified in the DHSS's 1960s-70s medical planning models where financial crises decimated the national hospital-rebuilding programme. Similarly, a lack of investment during Henry VIII's reign left hospital development void for many centuries until, to the credit of voluntary hospital management, fund-raising accumulated enough capital to build numerous London hospitals. Regarding 20th century hospital development, many public health acts were passed to assist with the building of healthcare facilities. Two significant acts in 1962 and 2000 revolutionised the spatial status of NHS hospitals (see Appendix D.34). The vital component concurrent between both acts was state injected financial investment. In continuing the 1980s trend to rebuild within 20 years, a new NHS building agenda should be scheduled to commence by 2020. If this is a possible scenario, then now is the time to prepare and research for the next generation of NHS urban acute hospitals.

The second issue regards standardisation which was designed to its utmost in post-WWII hospitals. Most examples were far from Aalto's vision of 'flexibility' and variety' that avoided 'the dull and monotonous use of reduplicated forms' (Pearson, 1978:150). As standardisation became a driving principle in late-20th century hospital design, ironically, NHS hospitals 'during the 1960s and '70s were to one off designs' (Smith, 1984:1513). This outcome was driven by uncontrollable economic forces and a constant demand for cheaper hospitals. Unfortunately, rigid and inflexible medical planning models were often created. For example, both Harness and Nucleus templates became void after spatial dimensions increased in response to medical technology changes. In addition, standardisation disallowed for site-specific hospitals in earlier DHSS models. In fact, standardisation was so inflexible that design models failed to accommodate for restrictive urban sites. Inflexibility was a fundamental difference between the Ospedale Civile and the Nucleus typology. While Le Corbusier created a flexible and co-extensive architecture, this standardised principle for spatial growth was not incorporated into any NHS Nucleus hospitals. Having wisely learnt this lesson, the standardisation of typologies was not as restricted in PFI hospitals but other areas of flexibility, such as, removable panels for expansion, may not have been suitably applied to respond to change.

The third issue is the unsustainable employment of cheap, low-grade materials. The thesis acknowledges this strategy is a short-term capital solution that ignores life-cycle building costs. Evidently, this flawed strategy was proven by the rebuilding of most Nucleus hospitals under PFI. Similarly, this fault underpins PFI contractual structures where architects' decisions are undermined. As a result, PFI hospitals have been produced with non-resilient substandard finishes which was highlighted as a problem throughout the PFI process. Architects felt they became 'passive servants of a procurement process over which they have no control' (Maxwell, 1996:11). In response, the NHS reconfigured design conditions within PFI contracts but the thesis questions if PFI hospitals will compare to longevity of 19th century hospitals. For example, clinical functionality may no longer exist in 19th century hospitals but the materiality of exteriors and finishes (glazed-tiled walls) remains predominantly intact. As a result, these durable buildings are often re-furbished and remain functional as flexible space within a hospital's masterplan. Therefore, in sharing architect John Cole's argument of 'long life, loose fit, low energy', a principle of quality architecture is central to a hospital's sustainable longevity (Cole, 2006:357).

The fourth issue is compromised functionality which resulted from spatial reductions. This was driven by consortia decision makers 'reluctant to invest in a dubious future' regarding built hospital space (Howard, 1972:255). Initial reactions are always to reduce cost by reducing area proportionally, based on a simple arithmetic of cost/sqm. However, from an experienced medical planners' experience, this naive approach does not automatically benefit a Trust's budgets as running costs far outstrip the capital investment of constructing hospital space (see Appendix D.35). This strategy, first introduced to reduce expensive pavilion typologies, has plagued NHS hospital design since 1948. For example, the use of HBN guidance to create spaces in the then Nucleus model did not cater for future spatial expansion, never mind its drastic policy that reduced all areas by 20%. PFI is guilty similarly where each space is microscopically scrutinised to decimal points of a square meter which leaves no flexibility for future spatial change. However, based on recent technology developments, PFI did incorporate one foresight; the addition of area to certain rooms but mainly large high-tech rooms. This approach would seem justifiable in the light of recent equipment size increases. However, if the nature of future technology is based upon ‘nanomedicine’, was spatial increase an appropriate medical planning solution? Considering that space is always of a premium cost, has PFI oversized hospital spaces? This issue is explored in Chapter 7’s discussion.

Collectively, nine medical planning post-1600revolutions were recorded. Notably, 80% of identified events have occurred since 1800 (see Table 4.9-10). Therefore, the thesis determines the origins of contemporary hospital design to date from 1800. This correlates with Richardson’s argument that specialist ‘hospital architects’ emerged at this time in response to an ‘increasing complexity of hospital planning’ (Richardson, 1998:11). The outcome produced a portfolio of 19th century pavilion typologies that were influenced by ‘miasmatic’ theories, Nightingale Wards and new architectural technologies. The NHS inherited this spatial legacy from which 20th century NHS hospital design evolved. New dimensions to contemporary hospital design emerged in due course from progressions in architectural services, departmental segregation, deep-space planning and vertical typologies. Under the influence of HDR, and architects, such as, Powell & Moya, the MOH and John Weeks, emerged new late-20th century medical planning models. By 2010, the paradigms of 20th century hospital design remain as current medical planning practice as no revolutions took place during the recent PFI process. To summarise, important architectural trends are determined as:

(i) Pre-1800 hospital typologies are not of concern to this study's technology concern

(ii) Short-term financial solutions undermine the sustainability of building life-spans

(iii) Spatial reduction should not compromise clinical functionality

(iv) Standardisation should be of the 'flexibility and variety' sort.

	Architectural period	Driving effects of architectural influences	Hospital example
4.3.1	C16th-20th	Nightingale Ward, pavilion typology, services	St. Thomas', London
4.3.2	1900-50	C20th modern architecture, new services, matchbox -on-a-muffin, deep-space planning, specialist hospitals amalgamate with NHS hospitals	Guy's Hospital, Braintree Sanatorium
4.3.3	British HDR	*Studies in the function and design of hospitals*, Nuffield Ward model, HBN documents, 'Hospital Street', Powell & Moya, MOH	Wexham, Greenwich
4.3.4	HDR results	Best Buy, Harness, Nucleus	Southends, Frimley, IOW
4.3.5	PFI	Money, contracts, healthcare policies, no HDR	UCLH, The Royal London

Table 4.9 Findings for architectural influences: Driving effects on hospital space.

Period of time	No. of events	Total no. of events	% of events	British Medical planning revolutions
Post-1600 (17%)	22	26	84.6	1. Royal & Voluntary hospitals
Post-1800 (8.8%)	21	26	80.8	1. Nightingale's Ward/ Pavilion 2. Sanatorium 3. Matchbox-on-a-muffin 4. Deep-space planning 5. NHS & specialists hospitals amalgamated 6. Nuffield Ward 7. Hospital Street 8. Nucleus/horizontal typology 9. PFI hospitals

Table 4.10 Table of analysed post-1600 &1800 architectural events and revolutions.

4.4 Chapter analysis

This chapter has mapped the historical events that have revolutionised hospital space since 1600 through the exploration of three hospital design influences (organisation, medical, architectural). An analysis of events is quantified in Table 4.11 which determined the post-1800 period as the most appropriate for exploring technology's relationship with hospital space.

Influence	Events	Revolutions	Arch influence	
Organisational	2	2	-	Not dominant
Medical	23	5	Knowledge & delivery	Not dominant
			Practice & Process	Dominant x 2
Architectural	10	5	-	Dominant
Total	35	12	-	Dominant x 3

Table 4.11 Analysis of chapter influences (400BC-2012): Quantified list of events and revolutions (see Appendix D.36-7).

While the NHS service is responsible for managing 108,113 general and acute beds (2005-6), it emerged that the NHS organisation does not directly affect hospital space (Wanless et. al., 2007:119). Hence, this influence has been discounted for the remainder of the study's research. Alternatively, from four medical influences, it emerged: a change in medical knowledge and delivery were 'instigators' of spatial change; changes to medical practice and processes are strong 'indicators' of spatial change. Furthermore, architectural influences were shown to affect hospital space and medical planning directly. Created through HDR, NHS hospital designers sought inspiration from architectural theories, such as, Aalto's standardisation methods and Weeks' indeterminate architecture. These conceptual precedents impacted on NHS hospital space but it was Le Corbusier's alternative medical planning solution that influenced the more numerously built Nucleus NHS hospitals. However, DHSS models failed to deliver sustainable and flexible solutions, ignoring that hospital buildings 'need to have inbuilt potential for growth and change' (Weeks, 1963-4:85). From findings, the thesis advocates; hospitals must be underpinned with flexible design solutions for future spatial unknowns.

A summary of important chapter findings includes: a mapped evolution of past and present hospital space; a set of key trends responsible for the current state of hospitals; changes to medical practice and processes are identified as strong indicators of future spatial change; HDR is central to creating responsive medical planning models; the failure of Nucleus hospitals was sourced from the use of cheap materials and dramatic spatial reductions that became inadaptable and inflexible to future change. From this chapter's findings, parameters for researching technology's impact on hospital space have been established. Achieving this thesis objective is further examined in the next chapter's exploration.

Chapter 5: Technology's relationship with hospital space

"The only way of discovering the limits of the possible is to venture a little way past them into the impossible"

Arthur C. Clark

5.0 Introduction

Chapter 5 continues with Part II's exploration of confirming technology's relationship with hospital space. Furthermore, this chapter participates towards achieving the thesis' second objective which is to identify medical technology's role in driving hospital medical planning. Both aims are achieved by presenting post-1800 technological revolutions and the examination of medical technology development within British hospitals. Medical technology as a hospital design influence is explored explicitly in this chapter. Explorations are divided into two periods: pre- and post-electrification. This is based on the pivotal event when consumable electrical energy[1] became available (c.1895) which transformed medical technologies, hospitals as well as the medical industry. The chapter begins with brief descriptions and spatial analyses of individual pre-electrical medical technologies. This is followed by a critique of pre-1895 findings which reveal medical technology's implications on 19th century hospital space. Thereafter, the same examination is conducted from a post-1900 perspective. Subsequently, an analysis of 20th century medical technology implications upon hospital space is discussed. The chapter closes by confirming the existence of a relationship between hospital space and medical technology. Findings also indicate that medical technology is a key driver of medical planning.

Medical equipment within this chapter is viewed from two spatial perspectives: as individual pieces; within a functional process. Analyses are informed by literature and photographic evidence, as secondary data is limited. Quantitative measurements are interpreted through current NHS HBN data. All chapter calculations are drawn from a standard set of calculated areas (see Appendix E.1). Areas for circulation space are not included within calculations.

---

[1] By the late 1870s, London's streets had electric lighting, the common light bulb was invented for consumer use (1878) and London Underground was starting to use electricity.

5.1 Pre-electrification technology

Healthcare delivery in the early-1800s was based upon Galenic medical practice. Procedures included cupping, bleeding and surgical procedures of ‘amputations, cutting for stone, opening abscesses and cataract’ (Barry & Carruthers, 2005:136). Minimal use of technology is recorded in both 19th century medical practice and hospitals. Five pre-electrical events emerge as revolutionary in developing pre-1895 medical technologies and hospital space

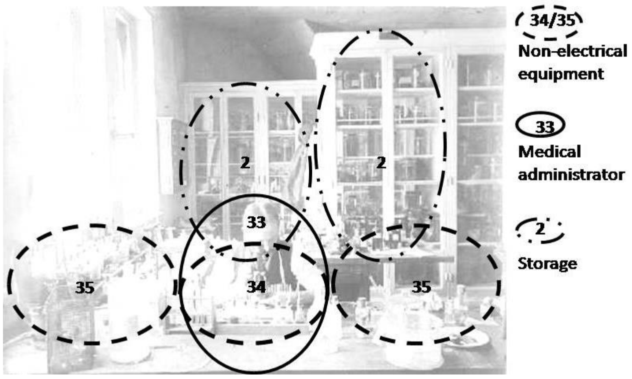
5.1.1 Growth of microscopy (post-1800s)

Since its invention (1600s), microscopy has played a strategic role in developing medical knowledge which, as a medical design influence, was identified as a main instigator of spatial change in section 4.2.1. Testing this principle with respect to microscopy, it is revealed that microscopy was a powerful tool in pioneering 19th century bacteriological, haematological and biochemical discoveries which increased clinical science procedures significantly (see Appendix E.3-5). A scattering of small laboratory spaces resulted in response to these scientific developments, as identified in the 1853 ground floor plan of St. Thomas’ (see Appendix E.6). Unified laboratories did not exist at this time as Foster & Pinniger argue:

> The beginnings of a clinical laboratory came into existence at St. Bartholomew’s Hospital about 1893 (Foster & Pinniger, 1963:339).

In cohesively arranging microscopic functionality, this event pinpoints a twofold revolution of medical planning significance.

The first revolution was the unification of hospital scientific functionality. This strategy was driven by new medical planning thinking that organised medical equipment centrally. The aim of this policy was to maximise the effective use of expensive microscopic equipment through the adjacent placement of multiple disciplines, for example, clinical chemistry and medical microscopy. Consequently, this grouping of medical equipment had wider spatial implications. The necessity for designated functional space led to the formation of a new Pathology department. This second revolution created a spatial entity that added a new dynamic to hospital medical planning. More importantly, a new principle for effectively using medical technologies was delivered through space. Combined both revolutions map a critical development in medical planning history. The origins of a new relationship between hospital space and medical technology were initiated through the efficacy of equipment, staff and utilised shared hospital space.

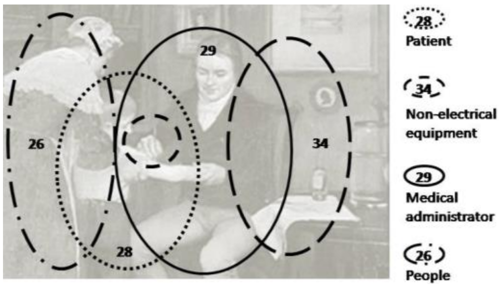


Left: Figure 5.1 Dr. Henry Fisher examining specimens in the Pathology Lab, c.1890s.
Right: Figure 5.1a Spatial analysis of Figure 5.1.

Sample 1: Data is extracted from photographic evidence depicted in Figure 5.1 to quantify how microscope use impacted on 19th century hospital space. Typical spatial requirements for operating microscopic technology are shown visually within a Pathology laboratory circa.1890s. Individually, a single microscope (0.019sqm) is not spatially demanding but requires additional functional area to deliver pathological procedures (see Figure 5.1a). Based upon HBN standards, the total functional area for the activities depicted is 400 times greater the size of a microscope (see Appendix E.7-11). Hence, this section reveals microscope equipment impacted on the creation of 19th century hospital spaces which led to the formation of a new Pathology hospital department.

5.1.2 Development of vaccinations (1796)

The discovery of the smallpox vaccination was a direct outcome from microscope equipment. This significant new treatment used medical technology as a tool to deliver improved public health (Richardson, 1998:3). The clinical success of this microbiological procedure is proven by its continued practice and positive anticipations for future medical biotechnologies (see Chapter 7).



Left: Figure 5.2 Edward Jenner administers a vaccine using a syringe (1796).
Right: Figure 5.2a Spatial analysis of Figure 5.2.

Sample 2: Administrating a vaccine requires minimal technology or high-tech medical space (see Figures 5.2-2a). However, based on the size of a syringe (0.00108sqm) and its calculated functional area, this medical equipment drives the creation of functional space by 3963 times its equipment size (see Appendix E.12-4). In this case, a wider spatial implication was generated through the large numbers of 19th century patients needing vaccination[2]. The result, therefore, of introducing vaccinations and syringe medical equipment was a need to increase 19th century hospital space substantially. For example, extra space in OPD was required for waiting and treatment areas while medical physicians and nurses needed more offices for general administration. As Richardson records:

> Out-patients rose steadily in the first half of the 19th century, and new hospitals generally included extensive out-patient departments, while older establishments found it necessary to build new ones. The Bristol General Hospital, for example,…in 1856-7,… included an out-patients' department large enough to accommodate over 300 people (Richardson, 1998:27).

---

[2] Smallpox vaccination was discovered in 1796 and was given official sanction in the *Vaccination Act 1853* where all infants were to be vaccinated.

This contrasts radically with St. Bartholomew's record of '45 out-patients weekly' in 1750 (Barry & Carruthers, 2005:51). The comparison between evidence uncovers the spatial growth of OPD between the 1750s-1850s. Additionally, extra Pathology space would have been needed to cater for the increased production of vial as well as storage for vaccines, syringes and cleaning facilities.

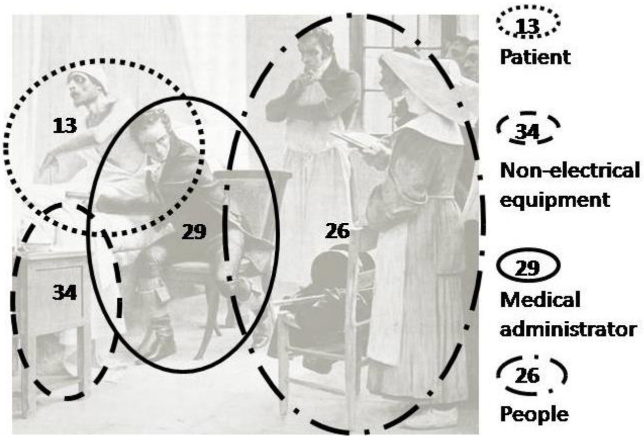
An apparent and relevant trend emerges in analysing the history of syringe technology; medical technology development influences a change in medical practice. Insight into medical technology's role in driving hospital spatial change is provided supporting Chapter 4's finding that evolving medical practice affects hospital space directly,

5.1.3 Patient observation and the stethoscope (1816)

The invention of the stethoscope signifies a turning point in the role and practice of physicians. More critically, the use of stethoscopes maps the source of the new 'clinical gaze' medical practice. Prior this revolution, minimal technology was used in delivering Galenic care.

> The doctor's job was mainly to manage the patient's condition – generally with some pretty ineffectual drugs washed down with a hefty gulp of the placebo effect (Porter, 2006:83).

The stethoscope revolutionised this practice by introducing patient physical examination. This first 'true' medical technology overturned classical humorism by shifting the treatment of individual patients to a clinical analysis of disease (Sanders, 2005:8; Foucault, 1963:107-8.). The spatial outcome from a change-in-practice was identified in Chapter 4 as twofold: large teaching hospitals were established; hospitals increased in size (see section 4.2.1). Additional hospital area consisted of increased ward sizes to accommodate for the growth in student rounds while newly introduced surgical observation required new dedicated OT rooms. Overall, the increase in room areas expanded the size of 19th century hospitals which was reflected spatially in late-1800s large pavilion type hospital typologies.



Left: Figure 5.3 Image portraying Laennec using the first stethoscope.
Right: Figure 5.3a Spatial analysis of Figure 5.3.

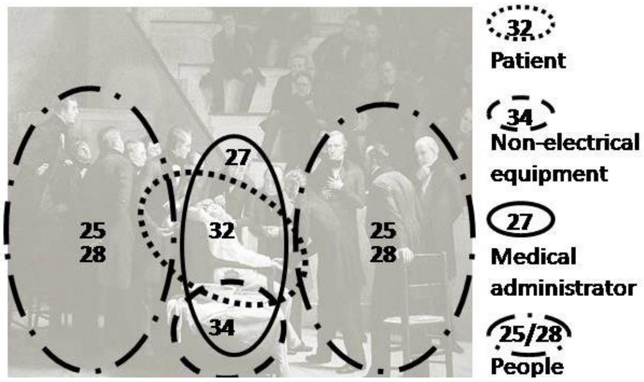
Sample 3: A stethoscope is a small hand-held mobile instrument which requires no fixed spatial requirements. However, this piece of medical equipment deeply impacted on 19th century hospital space. For example, a stethoscope size is estimated as 0.0038sqm. In comparison, its functional area of 11.04sqm is 2905 times greater its equipment size (see Figures 5.3-3a; Appendix E.15-7). This data is for one stethoscope only and a minute proportion of the quantity used within hospitals. Examples of its spatial impact include: new OPD examination spaces; new spaces for emerging roles, such as, physician's offices; larger and more Wards for increased patient observation. Built examples include St. Thomas' new ward wings in the 1830s and 1840s and the new OPD building at St. Bartholomew's, 1841 (Richardson, 1998:6; Barry & Carruthers, 2005:52). More significantly, the thesis identifies an important medical planning trend relevant to medical ETs where smaller and mobile technologies are forecast; small mobile pieces of medical equipment have wide implications upon hospital space.

5.1.4 Use of anaesthesia and sterilisation (post-1840s)

Surgical practice had benefited from two important events by the 1880s. The first occurrence was Lister’s 1867 introduction of antiseptics into surgery (Barry & Carruthers, 2005:140). Infection control standards were raised through a scientific understanding of sterilisation that assisted surgeons against the great enemies of bacteria, post-operative sepsis and septicaemia. The second event was the discovery of anaesthesia[3] (1846/1880s), which in combating pain thresholds, revolutionised surgical practice from one of amputation to invasive exploration[4] (Cottineau et. al., 1998:135; Porter, 2006:196-202). The outcome revolutionised surgical practice and the fundamental role of the hospital. Surgery was catapulted to the centre of the healthcare system which remains currently:

> Without surgery, or at least without a battery of invasive treatments, the hospital would lose its unique place in the medical system (Porter, 2006:176).

The spatial response was a growth in surgical areas and a profound reorganisation of hospital medical planning (see section 5.1.5).



Left: Figure 5.4 First operation performed under ether anaesthesia (1846).
Right: Figure 5.4a Spatial analysis of Figure 5.4.

Sample 4: The dimensions for anaesthetic equipment (1890) are recorded as 5” x 1.25” (Wulfing-Luer, 1897). This equates spatially to an area of 0.0077sqm. As a utensil used

---

[3] Inhalation anaesthesia (1844) and local anaesthesia (1860). Intravenous anaesthesia not used until (1932) (Cottineau et. al., 1998:Abstract).

[4] Anaesthesia allowed more surgical procedures to occur but deaths from surgery remained high until the C20th.

for surgical procedures, the functional area for anaesthetic equipment was calculated to be 2362 times larger its equipment size (see Figures 5.4-4a; Appendix E.18-20). Notably, this study acknowledges this spatial impact was not driven by anaesthetic equipment independently. Space for numerous spectators was also driving the size of OTs at this time. Still, anaesthetic equipment was the factor generating hospital space for the delivery and observation of operations rather than an outcome of surgical practice, which the presence of students represented. Anaesthetic equipment was also responsible for creating pre- and post-patient recovery spaces and support areas, such as, offices and changing rooms for theatre personnel. Wider spatial implications were experienced throughout numerous hospital departments: additional OPD areas were created to cater for surgical patients' appointments; extra surgical wards for increased patient numbers. Generally, the outcome from anaesthetic technology use was increased hospital GBA but the spatial impact was incomparable to its medical planning significance, detailed next.

5.1.5 Surgical investigations and new medical knowledge

Prior to1800, surgeons only treated diseased flesh. For example, tumours, fractures and gangrene were administered through ointments, bandaging, cleansing and pus removal.

> The scope of internal operative surgery they undertook was narrow, because they were well aware of the risks: trauma, blood loss, and sepsis (Porter, 2006:190).

Consequently, pre-19th century surgical practice required no specific spatial requirements and was undertaken predominantly 'on the kitchen table, on the field of battle, or below on deck on the warship' (Porter, 2006:176). Evidently this explains the non-existence of surgical spaces in pre-1800 hospitals but no specific data documents the introduction of surgical practice into hospitals. What literature does expose is the long-standing existence of hospital mortuaries which spatially expanded due to increased functional demands by the 19th century. Therefore, the thesis suggests that the progression from post-mortems to operations emerged from the flexible use of numerous adjacent dissecting teaching rooms. Eventually surgical procedures grew in volumes to justify the necessity for their own OT room. This spatial entity is represented in the hospital plans of St. Bartholomew's (1791,1841) and UCLH (1841) where new OTs were located adjacent to medical school dissection rooms (see Appendix E.21-2).

While new trauma knowledge was gained from the perils of 18th century wars, the development of surgical practice remained in its infancy until the 1860s:

> Before 1800 surgical operations are restricted to a minimum...In Glasgow in its first three years there were only three operations in 960 admissions (Barry & Carruthers, 2005:60, 135).

Three important events revolutionised 19th century surgical practice. The first event was the discovery of anaesthesia and sterilisation as mentioned in the previous section. The second revolution was new medical knowledge and its ability to catalyse surgical innovation. Sourced from a boom in printed medical literature, such as the *Journal de Chirurgie* (1791) and *The Lancet* (1823) surgical periodicals, the outcome increased the dissection of corpses resulting in the revolutionary 1858 publication of *Gray's Anatomy: Descriptive and Surgical Theory (Gray's Anatomy)*[5] (Steiner & Phillips, 1993:1). The third event was the development and standardisation of surgical technology. Originally, Barber-Surgeons' (pre-1745[6]) instruments resembled butcher shop tools consisting of cauterising irons, knives and amputation saws (Porter, 2006:190). Equipment was designed by practitioners and manufactured by blacksmiths, silversmiths and cutlers (Williams, 1978:1318). These non-fixed pieces of equipment were carried in cases by surgeons' personal 'box carriers' (see Appendix E.24). As documented at St. Bartholomew's Hospital, a box carrier 'would carry his instruments, clean the theatre

---

[5] Gray's Anatomy is a classic English-language human anatomy textbook. The first edition contained 750 pages with 363 illustrations (see Appendix E.23).

[6] In 1745, The Company of Surgeons split from the barbers (Porter, 2006:194).

and prepare dressings' until '1821 when each surgeon would appoint his own resident house surgeons' (Barry & Carruthers, 2005:51). Later in the 19th century, surgical brochures offered poor technical information.

> The practitioner who desires information relative to any particular surgical instrument or appliance,...is soon lost in a maze of unsatisfactory and confusing suggestions. Accurate descriptions are few, differentiations of patterns are almost unknown...which convey no information other than the name and price (Truax, 1899:7)

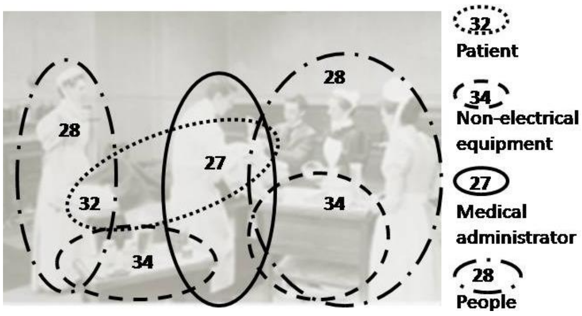
The outcome produced unstandardised sets of surgical equipment which led to fatal errors when surgical practice entered mainstream hospital care. These tools represent surgical 'technology' until the 1860s when equipment became standardised through improved manufacturing[7] (Williams, 1978:1317). The outcome of superior instruments initiated the beginning of contemporary surgical practice by allowing for increased and much improved surgical procedures.

Sample 5: Spatial requirements for surgical technology circa.1895 are depicted in Figures 5.5-5a. Measuring a typical surgical equipment set to be 0.111sqm, 170 times more functional area was required for this collection of mobile surgical equipment (see Appendix E.25-6). Whilst this area is small, the wider impact is of far greater importance here. Five spatial trends are identified as impacting on hospital space. The first trend results from new medical roles that emerged from novel surgical methods. Functional space was created to cater for new staff, such as, theatre nurses' offices and resident house surgeons' washrooms. The second trend introduced pre- and post-surgical areas in response to improved surgical practice while a third trend was the addition of OPD areas generated by extra consulting rooms for increased surgical patient visits. The fourth trend implicated on wards in two ways: additional beds;

---

[7] As surgery developed around a procedure and not the Surgeon, standardised equipment was introduced. Before Charles Truax standardised the manufacture of instruments (US), every piece of equipment was different. This allowed for huge and fatal medical errors. Aseptic instruments were made from old materials, such as, ivory, bone and wood. It wasn't until WWII that the use of plastics and disposals were introduced (Williams, 1978:1320).

separate surgical wards to reduce cross-infection between medical and post-surgical patients. The fifth trend resulted from the increased demands in support services. As a result, Pathology, Pharmacy and Laundry all needed additional functional space.



Left: Figure 5.5 OT at the Metropolitan Hospital, London (1896).
Right: Figure 5.5a Spatial analysis of Figure 5.5.

Important medical planning implications emerged in response to changing surgical processes and the growing multitude of additional and new surgically related spaces. Firstly, a new defined OT department was formed circa.1895. This new spatial entity revolutionised medical planning on two levels: added a large amount of high-tech space to the higher levels of hospitals; increased overall hospital GBA. Secondly, a shift in the existing medical planning model resulted from replacing ward areas with clinical activities to the top floor of hospital buildings. In doing so, complex medical planning relationships were introduced through the addition and rearrangement of staff, goods and patient routes. This outcome highlights the medical planning implications that can arise from changes to surgical practice. Thirdly, an important new relationship developed post-1850 whereby surgery and hospitals were ‘destined to become utterly interdependent’ (Porter, 2006:176). As surgical practice evolved to become central to hospital care, this transformation was manifested physically in the new and prominent location of surgical spaces. From the perspective of a medical planner, a rational decision to locate theatre rooms at roof level is justified as it receives the best north-facing daylight required for conducting surgery (Richardson, 1998:10). However, an alternative and deeper reason is underpinned by the newly elevated powers of surgeons.

Without this hierarchy, the thesis believes surgeons' opinions would have been ignored despite the logical benefits. Therefore, far from the 'kitchen tables' of 18th century surgery, pre-20th century surgical events emerged to revolutionise the role, function and spatial organisation of British hospitals.

5.1.6 Analysis of pre-electrical technology

This section mapped the development of pre-electrical medical technologies in hospitals (see Figure 5.6). A collective spatial analysis completes this section's exploration.

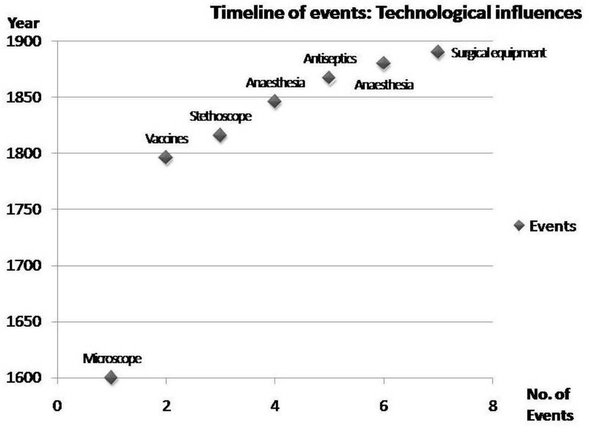


Figure 5.6 List of revolutionary pre-electrical technology events (1600s-1895).

The section opened by examining microscope use in hospitals. Its importance was found to be fundamental in establishing a core medical planning strategy; specialist functionalities were co-located to organise hospital procedures effectively by maximising the utilisation of expensive medical equipment. More significantly, this solution revealed that this novel approach to medical technology was delivered through the organisation and multifunctional use of hospital space. This finding establishes the initiation of an important inter-relationship between medical technology and hospital space.

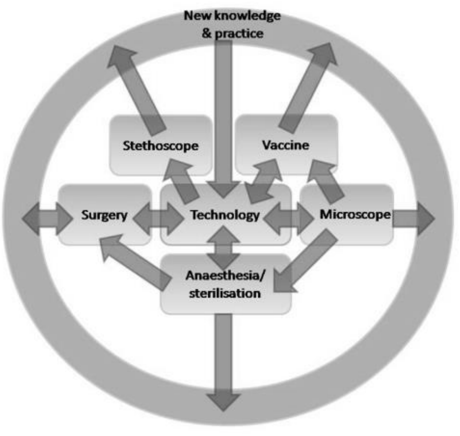
Syringe and stethoscope technologies were shown to increase space in a twofold manner. The first way generated area directly from introducing new medical equipment.

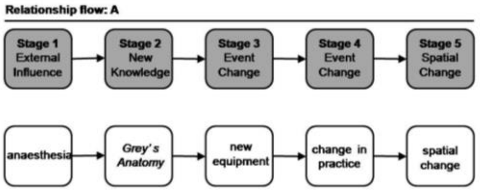
The second manner added space indirectly through technology's ability to transform medical practice. The variety in spatial impact ranged between: small units of increased equipment area; completely new and large teaching hospital facilities. Therefore, while both pieces of equipment were small, their wider impact was significant as non-fixed pieces of medical technology and raises two important medical planning trends: (i) the deep effect on hospital space from introducing small and mobile medical equipment; (ii) medical equipment mobility existed in 19th century hospitals.

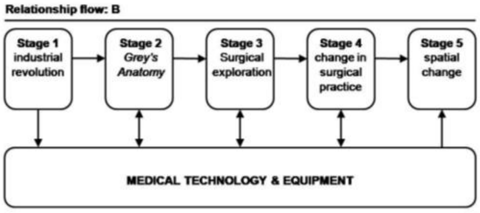
The developments in surgical technology increased the number and variety of procedures. Spaces were created to support new surgical activities which accumulated to form the OT department. Wide spatial implications resulted but profound changes to hospitals were also developing: surgical innovation was driving a fundamental shift in hospital functionality. The embodiment of this new relationship between hospitals and surgical practice was manifested through hospital space in the relocation of OT rooms. This major revolution announced the arrival of contemporary hospital medical planning by altering the principles of the then existing medical planning model.

From a quantitative perspective, the combined spatial impact of Samples 1-5 equated to 0.14258sqm for equipment area and 62.41sqm for functional equipment area (see Appendix E.27). None of this space existed prior the introduction of these medical technologies. On this basis, this study determines pre-electrical medical technology increased 19th century hospital space. Additionally, a review of functional areas shows that the impact of equipment ranged between 170 and 3963 times. Therefore, a standard ratio for medical equipment's impact on functional space proved inconclusive from this study.

Section findings are considered within Chapter 4's medical influence 'relationship flow diagram' to test medical technology's influence within the process of configuring hospital space. The outcome positioned medical technology as a Stage 3 factor in changing hospital space but this diagram did not reflect medical technology's complete effect as a design influence (see Figures 5.7-8a). A more precise diagram was produced from findings that positions medical technology as central to all stages of change (see Figure 5.8a).







Left: Figure 5.7 Relationship flow diagram: Medical technology as a central driver of developing medical influences. **Top Right Figure 5.8:** Relationship flow diagram A: Analysis of pre-electrical medical technology. **Lower Right: Figure 5.8a** Relationship flow diagram B: Updated analysis of Figure 5.8.

Sample	Impact of Medical Technology	Spatial and medical planning implications
1	Science	New laboratory rooms. Pathology established
2	Public health	Extra OPD, laboratories, non/clinical support areas
3	Medical practice	Extra OPD, wards & non/clinical support areas
4	Surgical practice	Extra OTs, OPD, wards & non/clinical areas
5	Surgical knowledge & practice	All departments effected by growth of new and additional areas. OT established.

Table 5.1 List of implications from pre-electrical medical technology findings.

Generally, areas affected in 19th century hospitals included Wards, OT, OPD and laboratories (see Table 5.1). This identifies the simple status of medical planning prior to consumable electrification. The radical changes that have occurred to hospitals and medical planning since this period are explored next in section 5.2.

5.2 Post-electrification technology

As a key component of modern technology, consumable electricity was revolutionary. The availability of electricity catapulted medicine into multiple dimensions. Six salient trends are examined to understand the impact of electrical medical technologies on post-1895 British hospital space.

5.2.1 Early-electrical years (1895-1950s)

This section maps the early years of electrical medical technologies. Three examples represent the technology types used to treat prevalent diseases at that time.

(i) Electrotherapy

The therapeutic benefits of ‘electricity’ had been known for many centuries prior to electrotherapeutics ascent into medical practice around the mid-19th century. Promoted as benefiting numerous ailments, such as, ‘stomach ache, rheumatism, and neuralgia’, the main use of electrotherapy was to instil muscle movement in the paralysed limbs of *tuberculosis* (TB) patients (Connor & Pope, 1999:61-4) (see Appendix E.37). Numerous accounts are recorded for the use of electrotherapies in hospitals. For example, the RLH records the financial difficulty of facilitating a ‘new expensive electrical treatment’ circa.1800 (Barry & Carruthers, 2005:75). Furthermore, at the new Charing Cross hospital (1823):

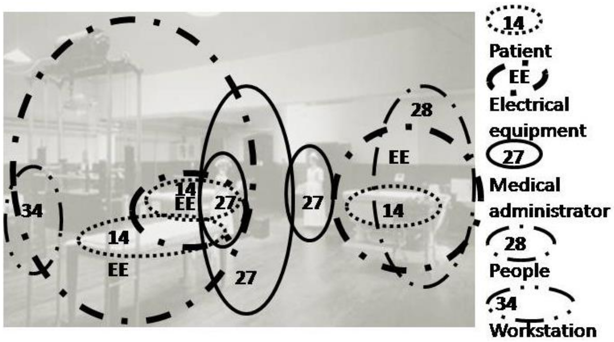
> The top-floor attics housed medical baths, and later an electro-therapy unit offering electrical muscle stimulation and continuous galvanic spasm (Barry & Carruthers, 2005:112).

By the late 1800s, the supply of electricity in batteries had evolved dramatically. This development led to the creation of many small portable medical devices. In response, galvanic specialities became practiced widely in hospitals until consumable electricity was introduced (Connor & Pope, 1999:61; Aronowitz, 2007:905). Ironically, the installation of electricity was the demise of electrotherapy as the practice was abandoned in favour of new ‘high-tech’ medical hierarchies; x-rays, surgical practice and pharmaceuticals. Electrotherapy was revived later in the 20th century where it has become a commonly used supporting device that uses ultrasound technologies for pain control management.

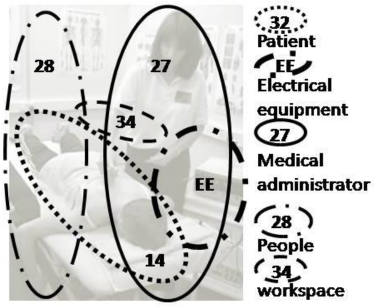
An alternative electric development was the invention of the electrocardiograph (ECG) machine (1911). Theoretically established by Galvani (1791), technological research culminated in Einthoven and Lewis’s ECG machine that brought technology ‘to the bedside and applied it to clinical medicine’ (Fisch, 2000:1739). By 1914, UCLH alone operated twelve machines for research and routine clinical work (Barron, 1950:721). Physically, the original floor-mounted ECG weighed 305kg. It required five personnel to operate and had restrictive patient accessibility. For example, ‘long connecting wires were run from the medical wards to the instrument’ (Barron, 1950:723). In one reported case, the measurement was one mile – the distance between Addenbrooke’s Hospital and its Pathology in Cambridge. This problem was rectified later when the ECG machine was fitted with castors (1920s) but it was the technology developments in 1936 that transformed ECG equipment radically (see Appendix E.32). The ECG became a 13.6kg easily transportable medical device. This new flexible dimension to delivering care can be accredited to the success of this mobile machine. Today, ECG technology remains embedded in daily NHS medical practice where billions of pounds worth of annual tests account for the necessity of ECG technology (Fisch, 2000:1737).

Sample 6: The Electrical Department (1910) at Great Ormond Street Hospital (GOSH) bears witness to the spatial implications from performing electrical treatments, such as, wax baths for impetigo and ringworm (Historic Hospital Admission Records Project

(HHARP), 2010a). Three pieces of equipment are depicted in Figures 5.9-9a. A galvanic bath and two treatment couches are located in one open space for staff and spatial efficiencies. The area calculated for the Electrical Department's equipment and functionality was 25.59sqm of previously non-existent hospital space (see Appendix E.28-9). Two important issues arise from data aside the addition of clinical space. The first issue is the significant growth in medical equipment size. At 1.3sqm, this area is 46 times larger than any of Sample 1-5's pre-electrical equipment. Therefore, it would appear that the difference between pre- and early-electrical technology is increased medical equipment size. This change was not a long-standing status as Figures 5.10-10a depict electrotherapy equipment in its current size (0.22sqm). This is six times smaller than the average equipment size in 1910. A second important issue to emerge was the proportion of functional area was altered in response to equipment sizes changing. To explain, Sample 6's functional area (1910) was reduced to six times greater when its equipment size increased. Alternatively, current electrotherapy equipment size is smaller but its functional area is 35 times larger (see Appendix E.30-1). Hence, this finding suggests that a relationship exists between changing medical technology sizes and its associated hospital functional space.

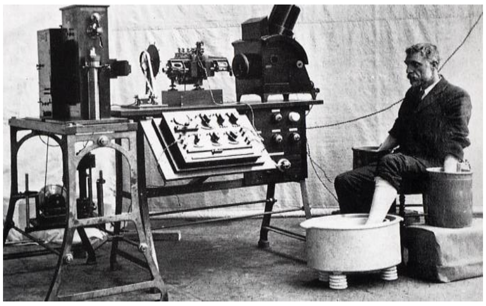


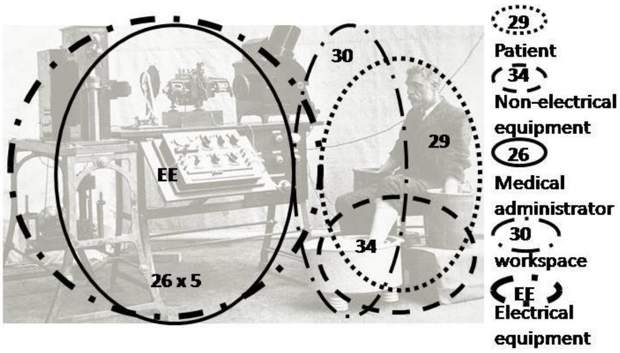
Left: Figure 5.9 1st Electrical Department, GOSH.
Right: Figure 5.9a Spatial analysis of Figure 5.9.



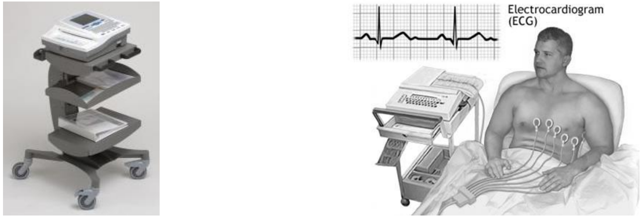
Left: Figure 5.10 Contemporary use of electrotherapy.
Right: Figure 5.10a Spatial analysis of Figure 5.10.

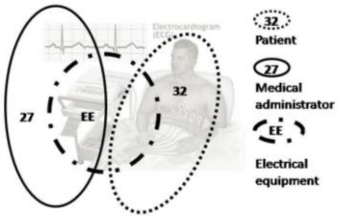
Sample 7: Figures 5.11-11a depict one of the first ECG machines. This image visually shows the change in size between pre- and post-electrical medical equipment. At 0.9375sqm, this ECG machine is 34 times larger than any of the pre-electrical equipment examined. On the other hand, Figures 5.12-12a depict a current mobile ECG machine which is only 0.1702sqm. This latest model is 18% of the original 1912 ECG equipment size (see Appendix E.32-6). Hence, evidence uncovers that ECG technology progressed in a twofold manner: (i) equipment size reduced overtime; (ii) medical equipment became mobile.





Left: Figure 5.11 Lewis's ECG at UCL, Medical School (1912).
Right: Figure 5.11a Spatial analysis of Figure 5.11.





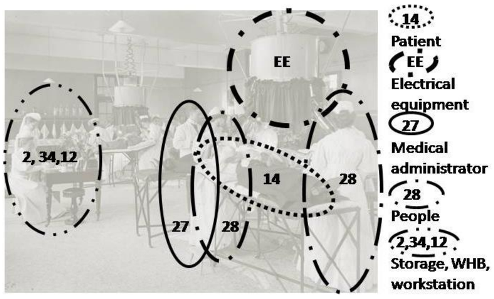
Left-middle: Figure 5.12 Contemporary ECG model and use of equipment.
Right: Figure 5.12a Spatial analysis of Figure 5.12.

The broader implications of incorporating early-electrical appliances into 20th century hospitals resulted in an increase of new spaces throughout OPD and support departments. From a staffing perspective, newly introduced roles resulted in new spaces, such as, electrotherapists' and cardiologists' patient examination rooms. These clinical spaces were created for patients accessing a range of new electrotherapy services. In response, larger OPD waiting areas were needed for those attending specialists' clinics as well as increased public conveniences for additional patients, staff and visitors. Huge increases in documenting clinical activity demanded extra administration staff and space. Most of these, designed as single cellular offices, were located in OPDs. The demand for extra non-clinical services increased as medical activity expanded. The outcome required more area for personnel, storage and equipment while workshop spaces for equipment maintenance and storage were also created. In many cases, the addition of new space was addressed through the refurbishment of existing spaces. A fortunate few hospitals, such as the RLH's OPD (1900s), built extensions to cater for much needed new hospital space. Generally, existing medical planning relationships were not required for changes at this time (see Appendix F.7).

(ii) Finsen Red Light Treatment (FRLT)

During the 1890s, FRLT was developed by Nobel laureate Niels Finsen for the dermatological treatment of smallpox and *lupus vulgaris* (see Appendix E.37). Previous treatments had employed light spectrum theory to filter harmful violet rays through the use of red coloured curtains or glass. Finsen replaced sunlight with distorted electrical light to develop medical electrical lamps (Morner, 1903). The outcome of FRLT equipment was so positive that 83% of Finsen's patients were cured completely. Long-term, FRLT treatment continued to be practised in hospitals until antibiotics eradicated both skin diseases in the late-1950s (Grzybowski & Pietrzak, 2012:454). This example of early-electrical equipment not only maps an event in 20th century medical technology, with respect to its short-lived lifespan, findings underpin one of many reasons why hospital space evolves overtime.

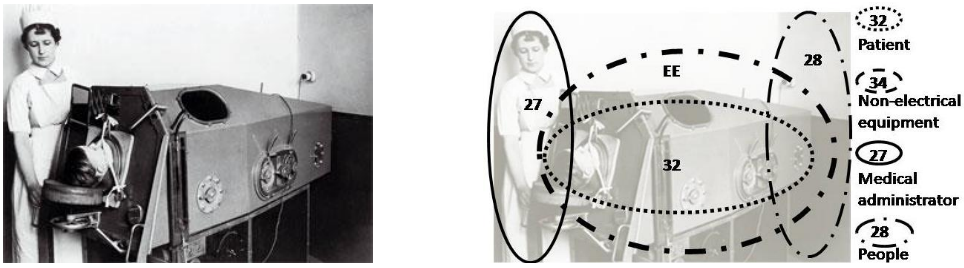
Sample 8: Pictorial evidence from Figures 5.13-13a show that functional space at ground floor level was still necessary to administer FRLT even though medical equipment was ceiling mounted. The spatial area for three treated patients is calculated as 31.33sqm. This is 139 times greater than the total of three FRLT equipment sizes (0.226sqm) (see Appendix E.38-9). In addition, the delivery of FRLT would have demanded extra functional spaces similar to those for ECG and electrotherapy technologies but a unique significance of FRLT equipment is the technology's transition away from ground floor. This arrangement frees up staff clinical workspace around couched patients and introduced a new spatial trend for late-20th century medical planning which was incorporated in the medical equipment planning of OT rooms and ICU bedrooms.



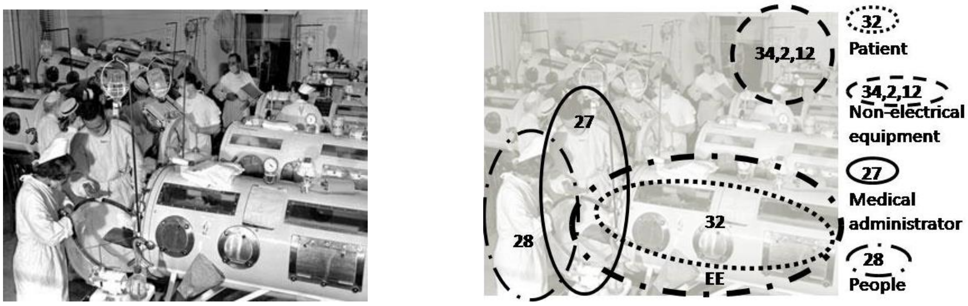
Left: Figure 5.13 FRLT room, RLH (1900).
Right: Figure 5.13a Spatial analysis of Figure 5.13.

(iii) Drinker Respirator

Poliomyelitis is an acute viral infectious disease that was epidemic in Britain in the early 1900s (see Appendix E.40). Most infected patients were treated in custom-designed sanatoriums until the 1930s. Access to fresh air and natural sunlight were dominant hospital design drivers in these hospitals. This model of care was overturned in 1934 when the Drinker Respirator or ‘iron lung’ machine was imported from the US. Invented by Philip Drinker and Louis Shaw (1929), the Drinker Respirator machine treated *poliomyelitis* patients by allowing them to breathe artificially (Meyer, 1990:490). This machine, located at GOSH, was the only one of its kind for some time but was available to other thoracic surgeons until the NHS invested in more equipment**.** Eventually, a polio vaccine was developed (USA, 1955) and introduced into Britain through a national immunisation programme (1958) that reduced the 6,000 *poliomyelitis* cases per annum (UK, 1955) to 315 between 1993 and 2003 (Torgerson & Torgerson, 2009:67).

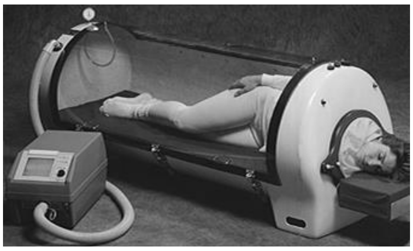


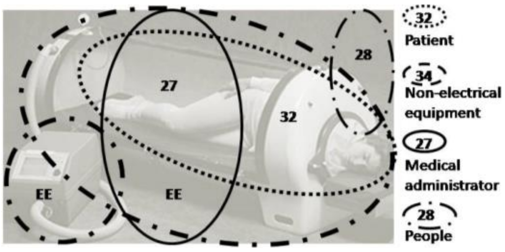
Left: Figure 5.14 Drinker Respirator, GOSH (1930s).
Right: Figure 5.14a Spatial analysis of Figure 5.14.



Left: Figure 5.15 Medical personnel tend to *poliomyelitis* patients (1950s).
Right: Figure 5.15a Spatial analysis of Figure 5.15.

Sample 9: The spatial implications of Drinker Respirator machines are depicted in Figures 5.14-15a. Evidently, the chosen strategy for operating numerous machines was to locate all equipment in one large open room. Quantitatively, this design was spatially efficient as calculations reveal a single machine in one room requires 6 times more functional area while seven machines in one space only required 3.5 times more functional area (see Appendix E.41-3). Of note, a low functional area rate was driven by the patient-to-machine relationship. This outcome was produced by patients lying within Drinker machines. In addition, extra spaces for ‘iron lung’ functionality typically included spaces associated with OPD, clinical and non-clinical support services as discussed in Sample 7.





Left: Figure 5.16 Treatment of patient in negative pressure ventilator (2000s). **Right: Figure 5.16a** Spatial analysis of Figure 5.16.

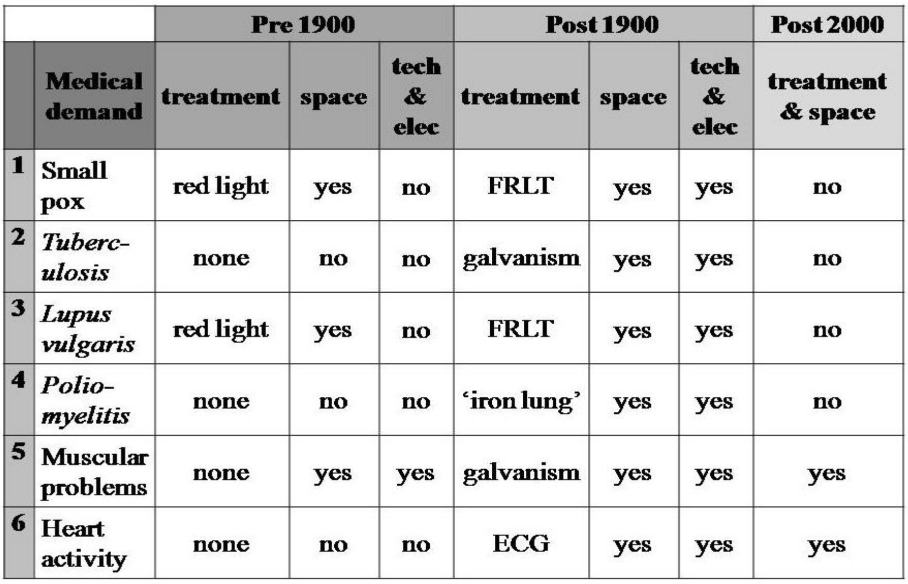
Two interesting points emerge from the ‘iron lung’s historical examination. The first point regards changing medical needs and the necessity for flexible hospital space. For example, the functional lifespan of the ‘iron lung’ was approximately 20 years. Therefore, spaces created for Drinker machines became obsolete by 1960. This finding supports the argument that medical technology affects hospital space. In this case, medical technology was responsible for driving the actual size of hospital rooms. The second point is the ‘iron lung’s’ long-term growth in medical equipment size. After 1960, the ‘iron lung’ was developed into a negative pressure ventilator, increasing its size to 3.2875sqm (see Figure 5.16-16a; Appendix E.44-5). This outcome offers an alternative perspective on medical equipment progression but does not alter medical technology’s status as influencing the configuration of hospital space.

(iv) Analysis of early-electrical years

The thesis recognises five key medical planning from this section’s analysis of early-electrical medical technologies in early-20th century hospitals.

The first trend is the addition of hospital space that resulted from new medical technologies. New spatial areas ranged from OPD spaces to a whole new ‘Electrical Department’. In quantifying the spatial impact of Samples 6-9, 3.77sqm of new hospital space and 72.81sqm of extra functional area were generated originally. Both measurements are for one unit only for each examined equipment. Therefore, these areas only account for the smallest spatial impact from each piece of equipment when they were introduced to function in a fully operational hospital.

The second trend concerns the ongoing change in medical equipment size which is presented by comparing original and current Samples 6-9 equipment sizes (see Appendix E.46). Of the equipment examined, 75% reduced its equipment size overtime: electrotherapy equipment by 34%; ECG by 82%; FRLT by 100%. A constant between all examined equipment is identified even though rates of change were determined as variable; as medical technologies progress, equipment size changes. This study emphasises the importance of this trend as a key component in driving the need for all hospital space to be flexible.



		Pre 1900			Post 1900			Post 2000
	Medical demand	**treatment**	**space**	**tech & elec**	**treatment**	**space**	**tech & elec**	**treatment & space**
1	Small pox	red light	yes	no	FRLT	yes	yes	no
2	*Tuberc-ulosis*	none	no	no	galvanism	yes	yes	no
3	*Lupus vulgaris*	red light	yes	no	FRLT	yes	yes	no
4	*Polio-myelitis*	none	no	no	‘iron lung’	yes	yes	no
5	Muscular problems	none	yes	yes	galvanism	yes	yes	yes
6	Heart activity	none	no	no	ECG	yes	yes	yes

Table 5.2 Thesis analysis: Changing medical demands and spatial impacts (1895-2012).

The third trend is recognised as technology's response to ongoing evolving medical demands. Table 5.2 lists this section's medical changes and their associated lifespan for medical technologies. As a result, the spatial impact of expired medical services resulted in obsolete space which further underpins the need for flexible hospital space.

The fourth trend is a medical planning strategy that creates large open spaces for operating multiple medical technologies to maximise staffing efficiencies, patient observation and teaching capabilities. This is no longer regular practice as a different approach took precedence towards the late-20th century. Single-occupancy rooms have been preferred for delivering patient privacy and dignity. This outcome generates costly spatial, technological and staffing inefficiencies. Current medical planning strategies evidently contrast with early-20th century policies for efficiencies which account for current increasing healthcare running costs.

The fifth trend concerns consumable electricity and its medical planning implications. The mobility of medical equipment was altered when energy became sourced from a fixed architectural element. A new restrictive relationship was formed between space, equipment and access to power. This is a critical event in hospital development and remains as the existing current status. This relationship causes medical planning difficulties but scope for its evolution is progressing with newly invented wireless technologies and its increased use in hospitals.

Overall, section findings inform the study of early-electrical medical technology's relationship with and nature in driving hospital space formation. Three general trends encompass the impact of introducing early-electrical technologies into hospitals: spatial addition; new types of spaces; reconfiguration of existing spaces.

5.2.2 Development of Radiology department

Since its accidental discovery (1895), x-ray technology has evolved radically to become central to delivering contemporary medicine (Roentgen, 1896). From its early beginnings, x-ray apparatus' were marketed as a new wonder machine fueling the idea that 'x-rays would soon be a part of everyday life' (Knight, 1986:14-6). Medical experts rushed to publish their findings claiming access to thoughts and eternal youth while curing blindness and later illnesses in the children x-rayed while still in their youth (Knight, 1986:22-3). The medical impact was so profound, new Radiology departments were established shortly afterwards. Further fields of Radiotherapy and Nuclear Medicine (NM) were developed in researching the true mechanics of x-ray technology (1920s). Each field contained their own specialist medical equipment, staff and hospital spaces. The 1960s computer revolution radically developed x-ray technology:

> The use of the computer to record, process, display and store diagnostic information has been the most important development in diagnostic x-ray technology (Hessenbruch, 2002:140).

Gradually, electronics 'led to a cornucopia of cheap and highly efficient analytical tools' which included sonography (1955), CT (1973), ultrasound (US) (1979), MRI (1980s) and PET (1990s) (Hessenbruch, 2002:137; Porter, 2006:208-9). CT technology was responsible for revolutionising non-invasive imaging by piecing multiple x-ray data together to scan internal organs. By the 1990s, CT technology had developed to allow for blood supply imagery (Wesolowski & Lev, 2005:377). MRI and US technologies were developed from this new concept in technology for the scanning of tissue, such as, the brain and spinal cord. Further to this, 1990s imaging technology developments took place in the form of 3-dimensional (3D) PET scanners. These machines were capable of investigating biochemical processes of anatomical metabolism. This medical technology caters for the prognoses of brain activity and tumours of stroke and epileptic patients (Wesolowski & Lev, 2005:378). Currently, image speed and resolution has improved the performance of radiographic equipment greatly to where 64-slice CT, 1.5 telsa MRI and US are now central to delivering NHS healthcare. Combined, all modalities have improved clinical diagnoses dramatically, transforming medical practice and the nature of hospitals into high-tech acute healthcare facilities.

The uptake of x-ray technology was almost instant throughout British hospitals. For example, St. Thomas' Electrical department records its use within one month of Roentgen's 1896 publication (Barry & Carruthers, 2005:44). By the 1920s, 'high-tech' medical equipment, its staff and expertise had been organised into a new spatial entity. The new Radiology department included rooms 'for therapy and diagnosis, the X-ray equipment itself, a generating plant and darkroom' (Richardson, 1998:11). The medical planning impact was the addition of area to the lower section of hospitals. Existing NHS estates were refitted during the *'make-do-and-mend'* period to accommodate for new radiology rooms (see section 4.3.2). By the late-1960s, the Radiology department had shifted to become central to hospital care but previous events were bypassed by post-1970s radical technology transformations. New radiology equipment, such as MRIs, struggled to fit into many existing hospitals by being 'elaborate, space-consuming facilities' (Miller & Swennson, 2002:134). A short-term solution was delivered through mobile MRI scanners parked alongside hospitals with spatial inadequacies. However, due to inflexible buildings and shortage of equipment financing, mobile x-ray technologies remain practised commonly in numerous NHS acute hospitals.

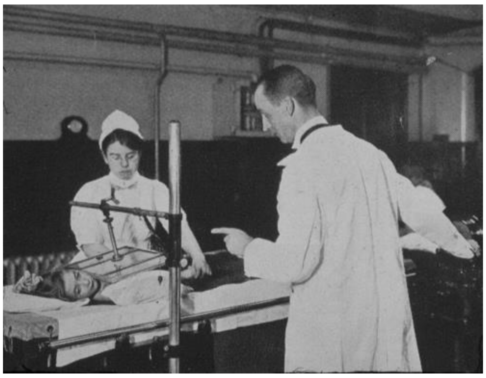
Since the 1980s, two spatial trends in Radiology (renamed Imaging) emerged: (i) mobile imaging bays; (ii) addition of a new 'Satellite Imaging' department. The first spatial trend is driven by imaging technology's new mobility which allows equipment to be no longer restricted to within its department. Mobile scanners can now be operated anywhere in hospitals but require additional space for storage and manoeuvring around patient beds or trolleys. The second trend is the recent addition of ‘Satellite Imaging’ next to A&E. This new development responds to the high proportion of hospital admissions requiring necessary imaging services (Goldman, 2003:4). This new spatial entity is pressurising an already busy and congested clinical area. For example, when a recent PFI project introduced 220sqm of Satellite Imaging next to A&E[8], the impact created spatial and medical planning complexities to both the UAT floor and whole hospital building.

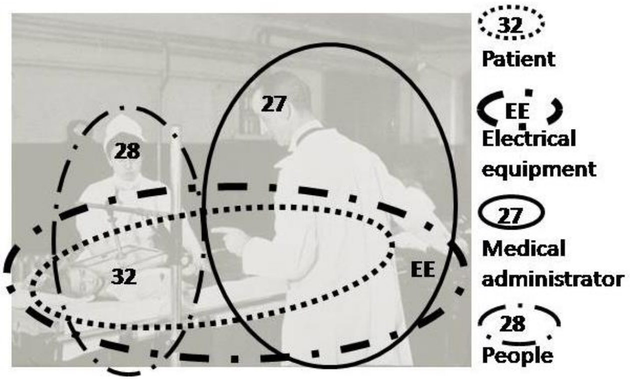
The dynamics of radiography have been revolutionised since its discovery in 1895. Technological progression has been responsible for shifting imaging services to its current central position within the healthcare system. This is represented by Imaging’s physical size, location and changing inter-departmental relationships as the department evolves its functionality to become a medical treatment as well as a diagnostics service.

Sample 10: Figures 5.17-18a typify the early use of x-ray equipment (1900-50) and spatially record a patient in a horizontal position with administrators operating an x-ray machine. Quantitatively, the area of x-ray equipment is larger than most previously explored medical technologies. For example, the equipment shown in Figures 5.17-17a is 1.08sqm while forty years later, equipment size had doubled to 2.16sqm (see Figures 5.18-18a; Appendix E.47-50). To cater for larger x-ray equipment, hospital rooms had to be increased in size. Therefore, the outcome of this investigation determines x-ray technology is a direct driver of 20th century hospital space.

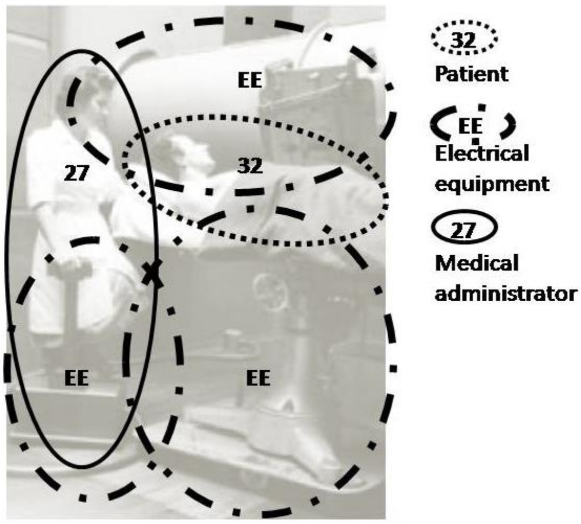
---

[8] Royal Liverpool University Hospital PFI project, Competition Design Stage (2011).



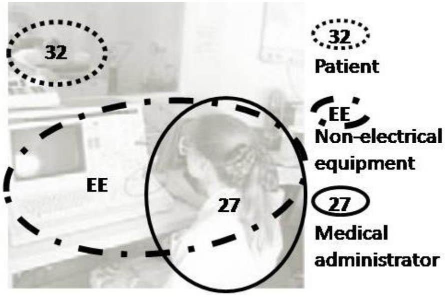


Left: Figure 5.17 1910, GOSH (X-Ray Department opened in 1902).
Right: Figure 5.17a Right: Spatial analysis of Figure 5.17

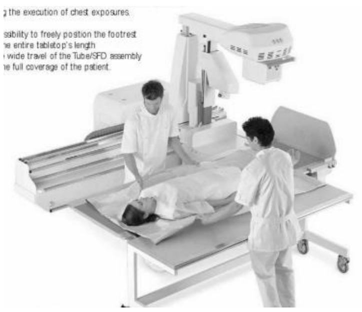


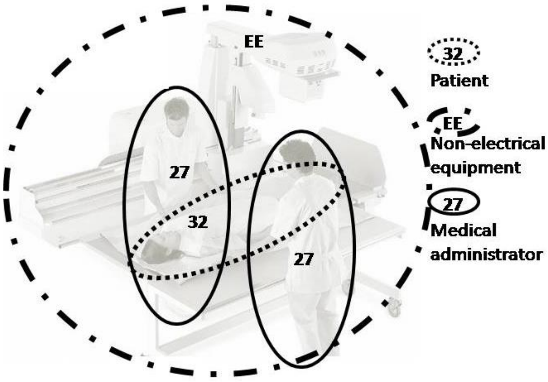
Left: Figure 5.18 1 million volt x-ray machine at The Barts (1950).
Right: Figure 5.18a Spatial analysis of Figure 5.18.

Sample 11: From 1950 onwards, Imaging rooms increased in number, type and size (see Figures 5.19-22a). For example, CT equipment required not only its own room but additional control rooms (5sqm) for computers (see Appendix E.51-2). Growth in medical equipment size has continued as imaging technologies developed. This is represented by the current area for plain film x-ray at 8.238sqm, CT area at 4.199sqm and MRI area at 5.005sqm (see Appendix E.53-56b). Interestingly, the area generated for functionality is now only fractional in comparison to pre-electrical equipment. For example, plain film is now 0.5, CT is 0.8 while MRI requires only 0.7 times the functional area of its imaging equipment size.

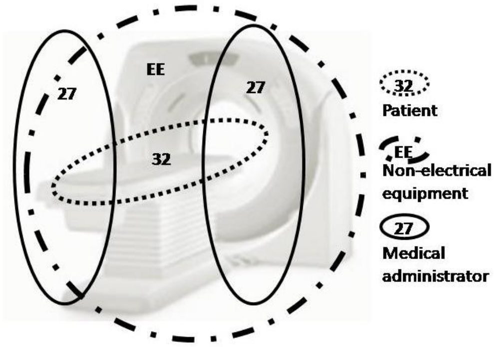


Left: Figure 5.19 Radiographer in control room, RLH (1993).
Right: Figure 5.19a Spatial analysis of Figure 5.19.

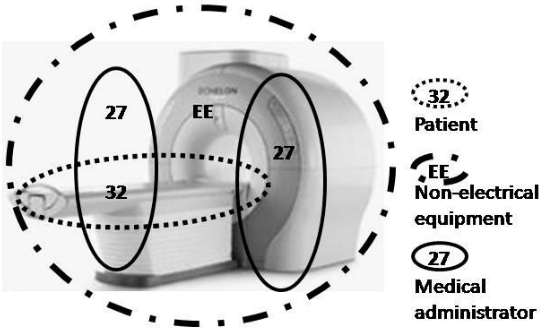




Left: Figure 5.20 Plain film x-ray.
Right: Figure 5.20a Spatial analysis of Figure 5.20.



Left: Figure 5.21 CT machine.
Right: Figure 5.21a Spatial analysis of Figure 5.21.



Left: Figure 5.22 MRI machine.
Right: Figure 5.22a Spatial analysis of Figure 5.22.

Sample 12: Current mobile imaging equipment requires 2.29sqm of area generally but these machines normally function within existing hospital spaces (see Appendix E.57-8). However, the flexible use of functional space needs to be offset against the spatial requirements for storing mobile equipment. Docking stations are sized at 2sqm each throughout hospital buildings. However, the creation of bays is far easier to accommodate than the relocation of a 30-50sqm high-tech imaging room with additional control and ancillary rooms when functionalities need to be relocated.

No x-ray technology existed prior to 1895. Therefore, the thesis determines that both imaging technology and its existence in hospitals have developed enormously since 1895. As both developments occurred simultaneously the thesis suggests that a relationship exists between imaging technology progression and hospital space. This section identified the impact of this relationship to be spatial growth and ongoing change. For example, scanning rooms have become cellular, larger and highly technical during their progression while the wider spatial impact includes the addition of areas to Medical Records, Administration and staff accommodation. More significantly, the creation of numerous new departments has resulted from x-ray technologies. These included Radiotherapy, NM, Satellite Imaging and Biomedical Engineering (Bio. Eng.). Each spatial entity has added space and complexities to the strategic medical planning of 20th century hospitals particularly in forming a new D&T hospital component. At present, Imaging is undergoing a transformation in functionality which is changing relationships between Imaging and associated departments. Furthermore, the mobility of imaging equipment is shifting the relationship between technology, power and space. This study recognises both evolving relationships are key components in evolving future hospital space as well as instigators for a new hospital medical planning model.

5.2.3 20th century surgical innovation

In *The Cambridge History of Medicine*, historian Roy Porter identifies 20th century surgical inventions and advances as the 'Golden Age' of surgery (Porter, 2006:202-7).

> The surgical revolution would have been quite impossible without all manner of technological innovations that have come to the aid of surgery, and indeed medicine at large (Porter, 2006:207).

Experience gained from both world wars, as Richardson argues, has 'consistently proved to be a stimulus to the development of surgical techniques' (Richardson, 1998:13). True to this argument, new surgical knowledge was created at this time through two major events: (i) intravenous induction agents; (ii) standardised surgical instrumentation. By the early 1900s, major advances in intravenous induction agents enabled surgical patients to fall unconscious quickly. By the 1940s, muscle relaxants were introduced into surgical practice allowing for the development of deeper explorations and high-intensive surgery. Parallel to these events was the necessary development of 19thth century surgical instrumentation. Charles Truax conceptualised and began manufacturing standardised surgical instruments to eliminate the copious fatalities during surgery. However, instruments continued to be made from old materials of ivory, bone and wood until plastics and disposables were introduced after WWII. This event signifies a revolutionary turning point in the creation of sterile surgical care which, from here on in, instigated major surgical innovations.

> Through technology, physicians would achieve the miraculous – and, in an age that believed in material progress more than in anything else, new and better machines seemed only a step away (Knight, 1986:26).

These 'machines', listed in Table 5.3, arrived in the form of numerous new medical technologies. As the 'efficacy of surgical techniques' elevated hospitals to 'the site of expert clinical treatment', preventative medicine became subordinate clearing the path for surgical domination. This event was represented by new typology forms that appeared in response to surgical innovation at this time (Hughes, 2000:26).

Year	20th century surgical technology inventions
1935	1st prototype heart-lung machine
1950s	Endoscope invented (1956), blood vessel replacements through material engineering (Freitas, 2003), 1st artificial pacemaker (1957)
1960s	Artificial heart valves, hip-joint replacements (Freitas, 2003)
1970s	Endoscopies in common practice, Cath. Lab.
1980s	Organ transplantations, oxygenators, dialyzers (Freitas, 2003) and artificial hearts (1982)
2000s	Micro-instruments and robotics allow for surgical day cases.

Table 5.3 20th century surgical technology inventions.

As surgical functionality expanded, strategic organisation was introduced to maximise efficiencies in cost, space, staff and medical equipment. On this basis, surgery developed into four defined categories of major and minor invasive surgery, invasive rigid endoscopy and surgical intervention (Miller & Swennson, 2002:160). The evolution of these surgical types is constant and alters inter-departmental relationships. For example, minor invasive surgery presently accounts for 75-80% of all surgical cases. In response, procedures are conducted predominantly within OPD or Day Surgery facilities which alter the original relationship between surgery and hospital space. While major invasive surgery remains central within the OT department, invasive endoscopy and surgical intervention (angioplasty, laser procedures) have also progressed to become day clinical procedures. The most noted spatial developments from this surgical trend include the establishment of Cardiac Catheter Laboratories (Cath. Lab.) and Endoscopy departments. Both departments are evolving currently in response to technological innovation which are blurring the boundaries between imaging and surgical procedures. This change-in-practice is shifting spatially towards a new medical planning model that merges surgical interventional rooms with the OT department. For example, a bi-plane angiography/integrated OT room at South West Washington Medical Centre represents this new type of hybrid room (see Appendix E.59). This latest medical planning trend is emerging from the developments in ‘minimal invasive’ technologies that reduce the scale of patient incisions while increasing patient recovery rates. Similarly, endoscopy has decreased the number of excisional and incisional biopsies radically:

> Even the most sceptical surgeons compare the magnitude of the impact of endoscopic surgery to the impact of anesthesia (Miller & Swennson, 2002:168)

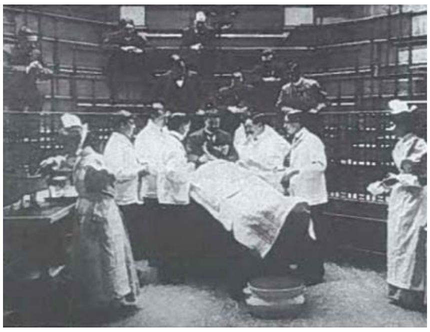
Other examples of this innovative technology include arthroscopy and lithotripsy but it is the recent robotic inventions that are revolutionising surgical practice presently (see Appendix G.9).

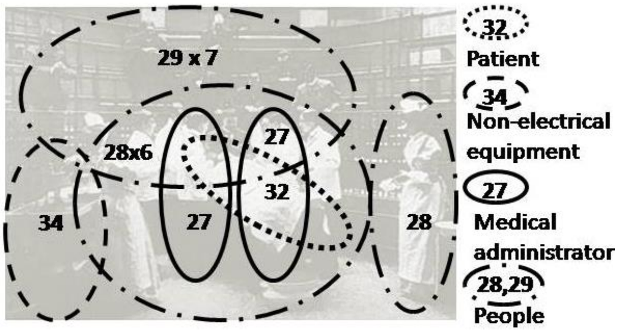
> The most common operation in cardiac surgery – coronary artery bypass grafting – can be done robotically, the surgeon performing the procedure while seated at a console near the operating table (Wilson, 1999:1)

This present situation of robotic use is changing surgical practice. As identified in section 4.2.5, changes in medical practice instigate future spatial change. Hence, the thesis recognises the possibility of change to future OT spaces which is fully discussed in Chapters 7-8.

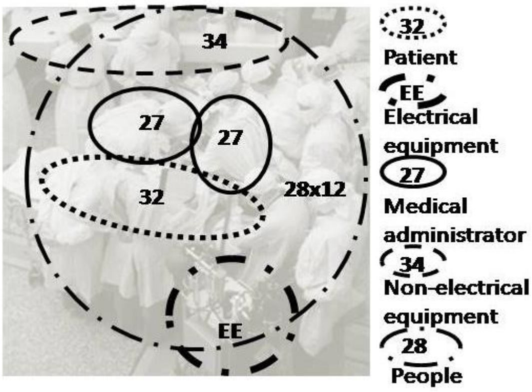
Sample 13: Evidently from Figures 5.23-24a, a large space for student observation existed in OTs while surgical administration consisted of minimal technology in 1898. The tiered viewing theatre is a typical arrangement for 19th century OTs but, as a model, was replaced by a flat-floored OT room by the 1920s. Spatially, this functional change reduced the ground floor area from 16.45sqm to 14.29sqm but the tiered seating was replaced with functional area for growing surgical teams (see Appendix E.60-3). In 1898, the only ‘technology’ present in OTs was non-electrical anaesthetic equipment. The size was calculated to be 0.0077sqm but, by the early-20th century, electrical anaesthetic machines had grown to 1.233sqm. These machines continued to grow in size whereby 1970s anaesthetic equipment, complete with gas cylinders, required 2.28sqm of space (see Appendix E.64-66). Thereafter, the evolution in surgical technology created highly computerised, technical, high-spec clean OT rooms (see Figures 5.25-26a). Surgical equipment became ceiling mounted**,** drawing from the concept for FRLT equipment, where suspended high-tech booms removed as many obstacles away from the working path of surgical team members. Ceiling mounted equipment is now standard practice in all OT rooms but current HBN guidance still allocates 7.548sqm at ground floor level for fixed equipment (see Appendix E.67). This is 98 times greater the equipment area calculated for 1898. This finding shows that spatial change occurred to 20th century OT rooms as a result of new surgical technology.

Numerous spatial events resulted from 20th century surgical technology developments. Events are underpinned by three spatial trends: spatial addition, ongoing changes and new types of space. The first major spatial trend regards the growth of OT room sizes. Rooms have evolved to become larger and highly technical spatial environments. For example, a general OT room is currently 55sqm while a specialist cardiac theatre is 63sqm (DHEFD, 2004;2006). However, these areas are likely to change in the face of increased imaging technology use in surgery. A second trend regards the addition of new rooms, such as, new clinical support rooms which comprise of clean and dirty utilities, prep rooms, pre-post recovery rooms, staff rooms as well as large storage areas created specifically for OT equipment. Elsewhere, extra rooms were added to support service departments to accommodate for increased OT procedures. These include extra areas for pathology testing and pharmaceutical production. A third major spatial trend is driven by the expansion of surgical functionality which has resulted in the creation of whole new hospital departments. Endoscopy, Cath. Labs. and Surgical Day Wards all originate from extra surgical needs. Each spatial unit has added to the size and form of 20th century hospital typologies. Furthermore, as surgical practice has progressed, inter-departmental relationships have evolved where the latest development is supported by the merging of surgical and imaging technologies. This important development is instigating a new revolution in the medical planning of urban acute NHS hospitals.

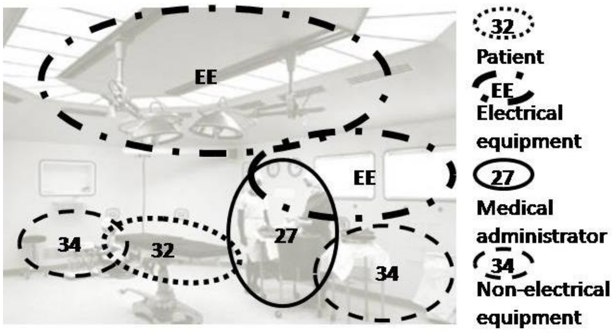




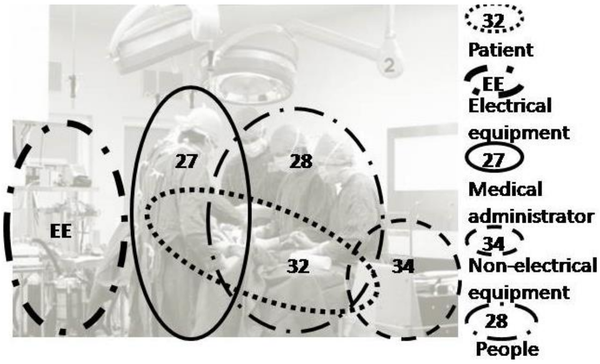
Left: Figure 5.23 Operation in progress, UCH (1898).
Right: Figure 5.23a Spatial analysis of Figure 5.23.



Left: Figure 5.24 OT room, RLH (1920).
Right: Figure 24a Spatial analysis of Figure 5.24.



Left: Figure 5.25 Modular operating theatre, Mile End Hospital (1971).
Right: Figure 5.25a Spatial analysis of Figure 5.25.



Left: Figure 5.26 Operation in progress, RLH (1993).
Right: Figure 5.26a Spatial analysis of Figure 5.26.

5.2.4 Laboratory (Labs.) Revolutions

Two laboratory departments, Pathology and Pharmacy, are explored in this section to highlight the developments of medical technologies within non-clinical hospital departments.

(i) Pathology

The most effective process for determining disease was post-mortem examination prior the use of stethoscopes or radiology technology. The demands for post-mortems and pathological services escalated rapidly as patient numbers expanded in 19th century hospitals. The outcome created new anatomical knowledge while scientific equipment became sophisticated. Space for conducting explorations was added as demands and funding arose. The first revolutionary development arrived when examinations transferred from cadavers to live bodies. Live blood and tissue samples were extracted for analyses to facilitate clinicians with their diagnoses and choice of treatment regimes. Laboratories evolved into a source of physiological and biological medical knowledge, as Porter argues, while 'the hospital was a place to observe, the laboratory to experiment' (Porter, 2006:157). The development of the Pathology department is mapped from St. Thomas' records:

> It was the addition of clinical bacteriology to the old medical microscopy and simple clinical chemistry that made the subject we now know as clinical pathology...it became apparent to the hospital staff that the arrangements for proper laboratory investigations on patients were inadequate and that they needed a central laboratory (Foster & Pinniger, 1963:339).

The need for a designated department, that consolidated all laboratory spaces to one location, gathered momentum by the 1890s.

> In 1896 the medical and surgical officers of St. Thomas's Hospital addressed an appeal for the centralized clinical laboratory...'it can hardly be doubted that in the immediate future a clinical laboratory...will be considered an essential part of all large general hospitals' (Foster & Pinniger, 1963:339).

Consequently, a clinical laboratory opened at St. Thomas' in 1897[9]. Such was the activity of this new department that 'a substantial new building for pathology was completed in 1902' (Foster & Pinniger, 1963:343). This study acknowledges this medical planning event as highly significant from the perspective of incoming medical ETs; the outcome from new pathological practice was the creation of new and additional laboratory spaces even though St. Thomas' had been rebuilt only a few years earlier (1881).

After the Pathology department was established at St. Thomas', Pathology departments became established throughout most UK hospitals. In this new department, pathologists examined all organs, tissues, bodily fluids as well as complete corpses in the process of micro-bacteriological diagnostics. Five subfields developed from the widespread impact of science upon medical practice (see Table 5.4). From these areas, the Pathology department became divided into sections of histopathology, cytopathology, bloods (bank, grouping, cross-matching), microbiology and specialist tests. Each subfield necessitates its own medical technology and spatial requirements. For example, specialist tests require 'containment level 3' status, sterile rooms. A plentiful of bench mounted equipment was invented from improved microscopic equipment. Alternatively, large floor standing pieces of automated equipment were invented to conduct batch sampling and specimen testing.

	Significant 20th century pathological discoveries
1	Microbiology (immunology)
2	Organic chemistry: New concept of deficiency **(**digestion, nourishment)
3	Endocrinology: Hormonal secretion, a new field of study of chemical messengers which led to discovery of insulin and diabetes.
4	Neurology
5	Genetics: DNA (1953), Human Genome (1986)

Table 5.4 List of typical 20th century pathological discoveries (Porter, 2006:165-75).

---

[9] Under Louis Jenner's directorship.

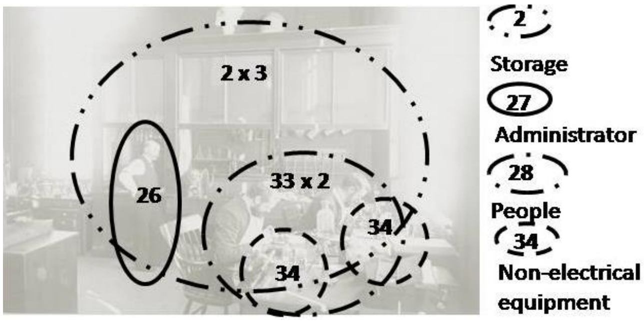
Pathology technology developed significantly during the 1970s to advance the speed of laboratory results and faster clinical decisions. This form of medical technology continued to improve to allow for real-time analysis. Consequently, many NHS hospitals are installing near-patient-testing (NPT) equipment presently. This is a new spatial trend that uses pathological equipment outside of its department and represents the expanding growth in mobile technology use in NHS hospitals (see Appendix E.70-70a). An additional type of technology assisted with accelerating pathological processes. The introduction of pneumatic tube technology delivers samples between Pathology and clinical areas. This technology is beneficial by reducing staff footfalls to depressurise hospital circulation spaces. This infrastructure technology requires its own functional space within Pathology as well as space throughout the hospital (1-2sqm each).

Pathology's growth since the 1890s has affected many hospital areas. New types and additional area have been added both inside and outside of the department. Too many to mention here, the following areas are representative examples: increased post-mortems spaces, new offices for microbiologists, clinical rooms for phlebotomy, large cold storage areas for specimens and spaces for NPT equipment. However, the thesis identifies Pathology as not a dominant medical planning driver particularly since pneumatic tube technology was introduced into hospitals. To explain, when hospital medical planning became complex post-1970s, Pathology resolved its operational issues through technology which assisted in decreasing extra circulation space and the medical planning problems associated with the delivery of goods.

Sample 14: To quantify the spatial impact of Pathology equipment, Figures 5.27-27a depict typical spatial needs for pathological administration c.1900. However, the spatial requirements for a Pathology department are recorded at St. Thomas', 1897:

> A large room 46x17ft., divided into two by a partition....each worker had his bench, drawer and sink, with gas and electricity laid on. One of the rooms was reserved for bacteriology and in the other room media were prepared, the blood and urine examinations made and the historical sections cut (Foster & Pinniger, 1963:340).

This new department required 81.54sqm of previously scattered or non-existent hospital space. To place this into perspective, St. Thomas' Pathology department is currently 7965.115sqm (see Chapter 6). This spatial increase is almost 1000% larger than 1897 which occurred concurrently to 20th century pathology technology development.

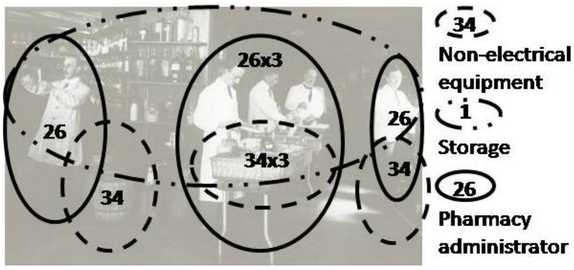


Left: Figure 5.27 Anatomy Laboratory, Boylston Street (circa 1900).
Right: Figure 5.27a Spatial analysis of Figure 5.27.

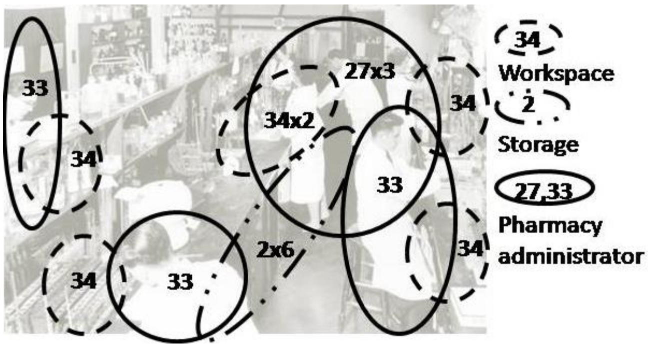
(ii) Pharmacy

Pharmacy departments existed in most British hospitals at the turn of the 20th century. Products produced and dispersed on-site included alcohol, castor and cod liver oil. Arsenic, opiates, cocaine and 'highly-explosive potassium chlorate' were also produced on-site with these remedies replaced eventually by 'superior' 20th century pharmaceuticals (HHARP, 2010b). As a direct outcome of new anatomical and physiological knowledge, and particularly 'germ theory', pharmacology experienced many revolutions, such as, the discovery of vitamins (1912) and insulin in 1922 (Porter, 2006:222-8). Eventually, in response to high medical demands, large-scale pharmaceutical manufacturing was contracted-out to private companies. This was a critical and constructive strategy that dealt with foreseeable pressures for pharmaceutical production and its impact on hospital space. This historical decision was proven to be apt, as in 1927, the invention of synthetic drugs transformed the pharmaceutical industry and the scale of manufacturing. Growth in pharmacology continued with many major breakthroughs during the 1940s, for example, numerous forms of chemotherapy were invented (Porter, 2006:232). However, post-WWII discoveries of antibiotics and penicillin affected medical practice deeply through its ability to control and manage human disease and pain. Major growth continued insofar that '50 percent of drugs used in the mid-1960s had been unknown only 5 or 6 years before' (NHS Trust Archives, 2008:panel9). Presently, medication remains central to the healthcare for patient wellness and recovery within hospitals where the future is forecast for further revolutionary advancements.

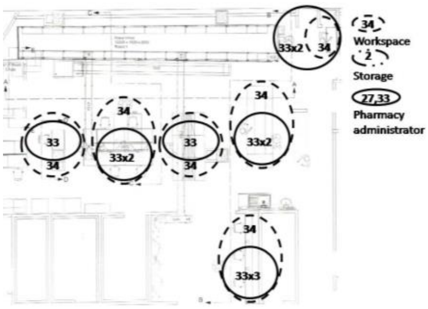
Sample 15: Pictorial evidence in Figures 5.28-28a show a functioning Pharmacy at GOSH in 1906. Little in the way of medical technology is visible in comparison with Figures 5.29-29a where the size, number and complexity of Pharmacy has grown by the 1930s. This correlates with the post-1910s pharmaceutical changes which required additional area to support new equipment, workers and functional area. This increase, approximated to be 23.7sqm, is based on the generic unit of space required for each pharmacist's workstation pictured (see Appendix E.71-4). Today, workstations remain similar but it is to the latest robotic dispensing equipment that is directing the configuration of hospital space in Pharmacy departments (see Figure 5.30-30a). These robotic machines are custom-made to suit the needs of each hospital's pharmaceutical demands. These vast machines, such as, the robot at Pembury Hospital (19.93sqm), directly affect the size and form of hospital space while readjusting the medical planning of hospitals if placed in Dispensaries at ground floors (see Appendix E.75-7).



Left: Figure 5.28 GOSH Pharmacy (c. 1906).
Right: Figure 5.28a Spatial analysis of Figure 5.28.



Left: Figure 5.29 Birmingham Hospital Pharmacy (1950s).
Right: Figure 5.29a Spatial analysis of Figure 5.29.



Left: Figure 5.30 Pharmaceutical robot located in production Pharmacy’s only.
Right: Figure 5.30a Spatial analysis of Pembury Hospital pharmacy robot.

Currently, Pharmacy is divided into two distinct areas: Dispensary and Main Pharmacy. Clinical trials are conducted in either Wards or OPD spaces. Recent hospital designs locate the Dispensary adjacent to hospital entrances to improve customer accessibility. This has been achieved through pneumatic tube systems that transfer products safely while effectively using expensive Pharmacy staff. The latest operational model for Pharmacy is the use of ‘Satellite Pharmacies’ to decrease time delays and staff travel distances. These new units localise pharmaceutical stocks adjacent to busy clinical areas throughout the whole hospital where needs be. Main Pharmacy areas consist of spaces designated to drug receiving, packaging and storage. Pharmaceutical production is conducted in aseptic suites consisting of space hungry high-spec clean rooms. The spatial impact of pharmacy technology is similar to the development of Patholgy which is the formation of new and additional spaces, such as, radio-pharmacist changing rooms or clinical trial offices**.** While the Main Pharmacy space has become more technical, functionality remains in a large open-planned room with cellular rooms surrounding its perimeter for new specialities and disciplines. Further afield, new additional spaces range from observation rooms in Wards to prep rooms in OTs for distributing medication. Historically, the most important medical planning event, with reference to this thesis' concerns, was Pharmacy's conceptual strategy to out-source manufacturing in the 1920s. This alternative medical planning solution was a logistic and spatially efficient approach put in place to deal with emerging medical developments.

To summarise section findings, HBN guidance for a typical Pathology department that caters as a service network provider is 3337.8sqm in area (DHEFD, 2005). Alternatively, aseptic production remains on-site in most large NHS acute hospitals resulting in the need for Pharmacy to be 1039sqm as per HBN14 guidance (DHEFD, 2007a). Both areas of laboratory accommodation did not exist or barely existed prior to 1895. Therefore, this section shows laboratory technology development took place simultaneously with hospital spatial growth.

5.2.5 Development of acute patient care

A brief outline of acute care development supports the study's investigation of medical technology growth in hospitals even though patient care is not a central concern.

(i) Intensive Care Unit (ICU)

When technology advanced surgical practice to treat and cure patients successfully, palliative care no longer remained the only form of hospital care. A new medical technology was invented to assist with patient care developments. Previously discussed, the ‘iron lung’ was made redundant when pharmaceuticals eradicated *poliomyelitis.* Its technology was developed into a mechanical ventilator for respiratory control (Miller & Swennson, 1995:182). This upgraded technology resulted in a new critical care practice which stabilised patients in post-operative or critical care conditions (c.1950s). Logistically, it became desirable to centralise all of these patients, their staff and technologies at one location. Therefore, as an outcome of new medical technologies and HDR, a new ICU service with specialised staff was introduced into NHS hospitals (1960s). These ICU nursing units became highly technical and have since developed into highly-intensive acute care units. This instigated the spatial creation of similar acute care departments: High Dependency Unit (HDU); Critical Care Unit (CCU); NICU. All are driven by the centralisation of medical technologies dedicated to stabilising high-level acute patients in one location.

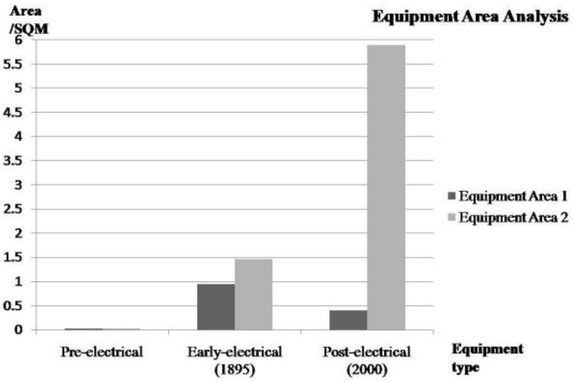
(ii) Accident and Emergency (A&E)

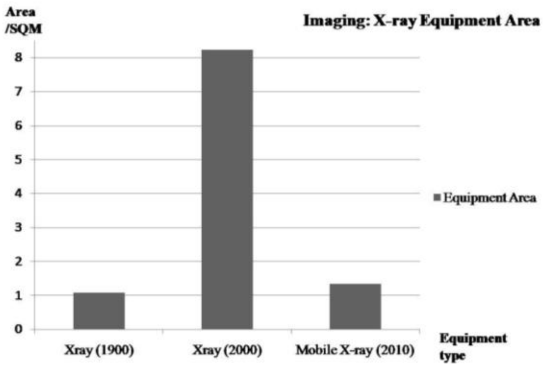
As a recent development in British healthcare delivery, the A&E department only came into existence from the accumulation of technology developments. For example, access to improved x-ray technology and surgical instrumentation increased the survival rates of patients in critical conditions. After the *EMS Act* (1939) established an ‘emergency’ service, acute care was introduced into NHS hospitals. This new department allowed for patients to be admitted into a dedicated area that treated and observed emergency sick patients. Since then (1950s), A&E departments have grown to become UAT centres. Recent trends in design have been influenced by complicated acute trauma procedures, delivered by multi-disciplinary teams that need access to cutting-edge imaging equipment. Therefore, with the introduction of mobile technologies, a trend for using scanning equipment within A&E departments was established to eliminate the troublesome need for bedded patient transfers. Area was added for mobile medical equipment but as a new model for ‘satellite imaging’ emerges, the dynamics of planning A&E departments continues to evolve and expand spatially.

Based on current HBN guidance, A&E departments equate to 1878.5sqm of previously non-existent space (DHEFD, 2007b). Similarly, 1792.4sqm is now required for a CCU (16 bed unit) department. Both examples support the argument that medical technology creates the need for urban acute hospital space.

5.2.6 Analysis of post-electrical technology

The development of post-1895 medical equipment was mapped through Samples 6-15. A collective spatial analysis of this section reveals four main important findings.



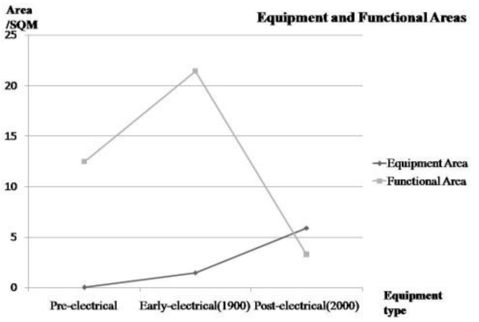


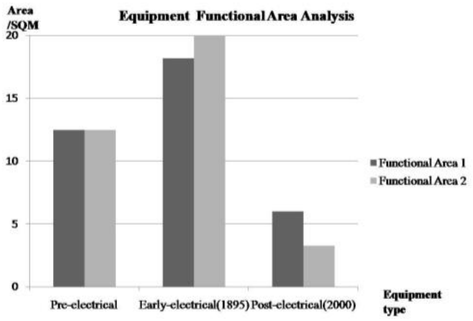
Left: Figure 5.31 Pre- and post-electrical equipment area analysis. **Right: Figure 5.32** Development of x-ray areas (see Appendix E.78-9).

(i) Increase in medical equipment size: Averages for pre- and post-electrical medical technology sizes were graphed in Figure 5.31 for comparison. Data clearly identifies an increment in equipment size between 19th and 20th century medical technologies. A direct outcome from this finding was the creation of extra hospital area for much larger 20th century medical equipment.

(ii) Evolving medical technology sizes: The thesis observes that medical technology size increases before it decreases in equipment size during the course of its evolution. For example, the history of ECG, electro-therapy and x-ray technology all experienced this evolutionary change (see Figure 5.32). Therefore, even without ‘nanotechnology’, medical technologies seem to follow a pattern of equipment size reduction as they progress. Challenging this theory is the recent increase in mobile CT size but this medical technology is only in its initial stages of development. Therefore, the thesis believes that future mobile CT equipment will be smaller in size since the difficult challenge of mobility has been achieved.

(iii) Evolving proportions of medical technology size to functional space: Functional area for medical technology was found to alter after equipment size changed (see Figure 5.33-4). This relationship reached a pivotal point post-1970, when, for the first time, the proportional rate of medical technology was greater than its functional area. This significant event identifies when room sizes became dictated by medical equipment and maps a revolution in medical planning history when medical technology became a dominant design factor in configuring hospital space.





Left: Figure 5.33 Growth of medical equipment and functional areas.
Right: Figure 5.34 Proportion of medical equipment area to functional area.

(iv) Effects of medical technology development on medical practice: The extent to which medical technologies had grown was reflected by its hierarchy in 20th century hospitals. For example:

> The x-ray machine led the way to the technical, machine-orientated medical practice we are familiar with today (Knight, 1986:30).

Numerous departments were created specifically for medical technology use post-1900, in comparison to the anatomical divisions of late-19th century hospital space. Hospitals became operational and technical where the reliance upon technology dominated the provision of care. As new medical technologies emerged, the number and type of hospital space multiplied in two ways (see Table 5.5): (i) existing departments expanded, such as, OT and Pharmacy; (ii) new departments were created, such as, Imaging and Bio. Eng..

Sample No.	Post-electrical Technology	Revolution in	Spatial implications
6-9	Electro-therapy	Technology, therapeutic care and monitoring	New OPD and rehab spaces created. Extra spaces for support required in Pathology, Administration and Laundry. Areas for storage, maintenance and staff change added throughout the hospital.
10-12	Radiology	Technology, Diagnostics, recent treatments	New Satellite/Imaging departments created. Storage for mobile equipment and administration added, such as, PACS, Bio. Eng. and staff accommodation added.
13	Surgical	Surgical technology, MIS	OT suite increased. New CSSD and Surgical Day Wards added. Extra space required in Pathology, Laundry, OPD and Wards. Additional staff and cleaning areas throughout the hospital.
14-15	Laboratories	Laboratory technology, diagnostics, pain and disease management	New clinical Pathology department formed. Extra spaces required for administration, testing, production and storage. Increase in size to Pharmacy department. Extra spaces added to OPD and Wards. Area for storage, maintenance, staff and administration added throughout the hospital.

Table 5.5 Tabled analysis: Chapter 5's post-electrical technological events.

Post-1900 surgical innovation supported the rise of the OT department to its central and current position within NHS hospitals. Driven by medical technology progression, the 'Golden Age of Surgery' flourished to dominate 20th century healthcare and hospital space due to its substantial proportions for each OT and adjacent ancillary rooms. Recent medical technology developments, however, are dissolving this department's boundaries through improvements in imaging and minimal invasive technologies. These changes to surgical practice are reforming inter-departmental relationships which will create transformations that will lead to a major medical planning revolution.

Current evolving models of care are being assisted by new mobile equipment which emerged as a concept not unique to late-20th century hospitals. Findings identified that mobile equipment existed prior the use of consumable fixed energy and was central to early-20th century developments in ECG technology. This trend towards mobile medical equipment creates a shift in the relationship between delivering care, technology and hospital space. For example, developing laboratory equipment is of significance to NPT mobility which is evolving pathological functionalities to be contained no longer within Pathology. The thesis recognises this shifting relationship to be crucially important to assisting in future hospital medical planning.

The thesis identifies seven major trends from post-electrical medical technology developments that are relevant to future medical planning:

(i) Numerous new departments were created as new technologies emerged

(ii) Pharmacy's alternative medical planning solution for future change

(iii) Electricity became a fixed architectural element post-1900

(iv) Increased proportion of medical technology size to hospital space (post-1970s)

(v) Medical technology size declines during the course of equipment evolution

(vi) Mobile equipment changes the relationship between delivering care and space

(vii) Blurring of boundaries between surgical and imaging technologies is currently reforming the strategic medical planning of hospitals.

5.3 Analysis of chapter findings

This chapter's specific divided examination has magnified the difference between 19th and 20th century technological developments. Numerous trends emerged regarding medical technology types and sizes while equipment mobility was observed as an ongoing trend rather than a recent technology development. Generally, investigations have provided spatial evidence that proves:

(i) 20th century medical equipment sizes are larger (0.4-5.9sqm) than pre-electrical medical technology (0.0285sqm) (see Figure 5.35-6)

(ii) Growth in medical equipment size is inconsistent and can become void (see Figure 5.37)

(iii) The proportion of total area for pre-electrical medical equipment size was fractional (0.228%) in comparison with 20th century medical technology sizes (64.3%) (see Figure 5.38).

Significantly, it emerged that small medical instruments can transform medical practice, organisation and space. However, the thesis determines; small medical equipment instigates spatial creation rather than drives the particular sizing of hospital space.

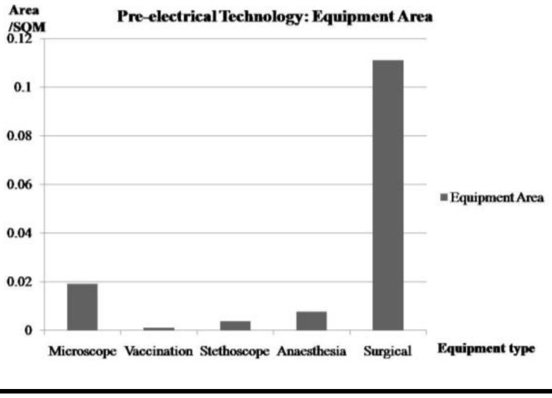


Figure 5.35 Analysis of pre-electrical medical equipment sizes (see Appendix E.27).

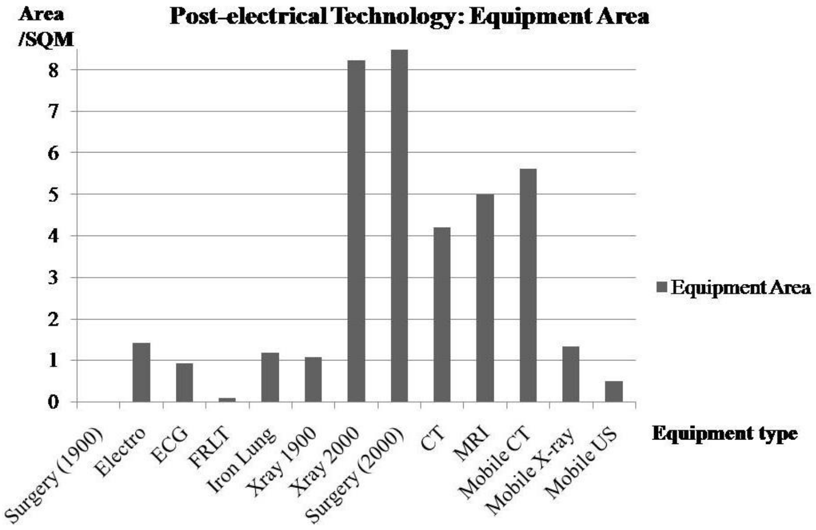
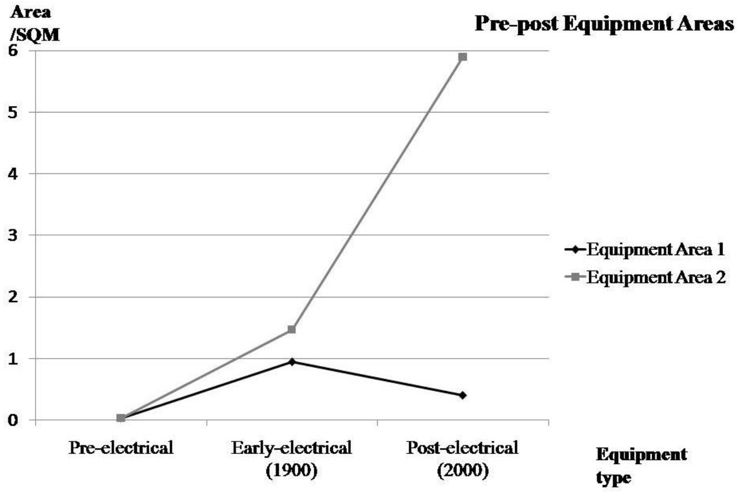


Figure 5.36 Analysis of post-electrical medical equipment sizes (see Appendix E.78).



Left: Figure 5.37 Analysis of pre-post electrical medical equipment sizes (see Appendix E.79-82).

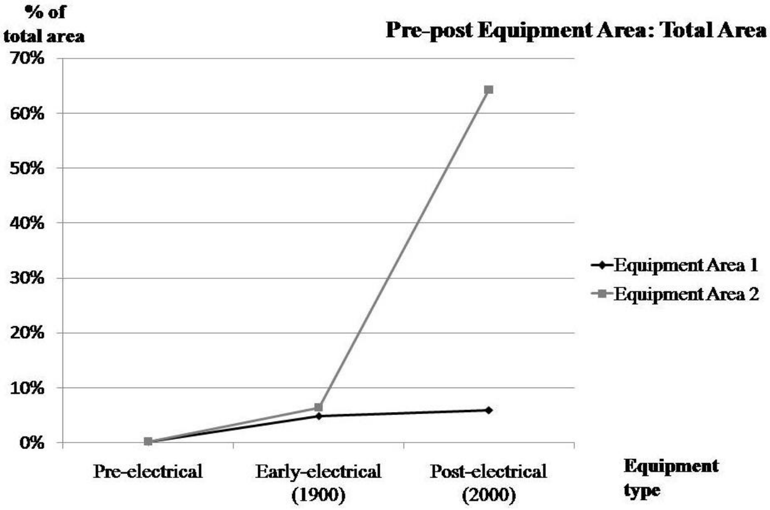


Figure 5.38 Analysis of pre-post electrical medical equipment size as a proportion of total area (see Appendix E.83-5).

As per Chapter 4 and 5's findings, a minimal amount of medical technology existed within a few 19th century hospital departments. For example, pre-1895 hospitals consisted of Wards, OPD, mortuary theatres and a scattering of laboratories. The thesis acknowledges that major innovations took place in surgical and x-ray technologies, such as, the numerous radiological inventions listed in Table 5.6. As each new medical technology was introduced into practice, medical equipment and its functionality required dedicated hospital space. The accumulative affect was the formation of new hospital departments some of which were technology based. A splurge of new departments opened throughout the 1900s as medical technologies developed extensively (see Figures 5.39-41). An examination of events was required to determine the relationship between findings. Rates for medical technology progression were mapped onto the growth of hospital departments. Evidence mapped the creation of new hospital departments occurred concurrently with medical technology progression between 1800-2010 (see Figure 5.42). This finding uncovers; a strong relationship between medical technology and British hospital space has existed since 1895.

Equipment	**Radiology Equipment in Existence**		
	1900-50s	**1970s**	**1980s+**
Plain film x-ray	yes	yes	yes
CT	-	yes	yes
MRI	-	-	yes
Control	-	yes	yes
Mobile	-	-	yes

Table 5.6 Development of Radiology equipment (1900-2010s).

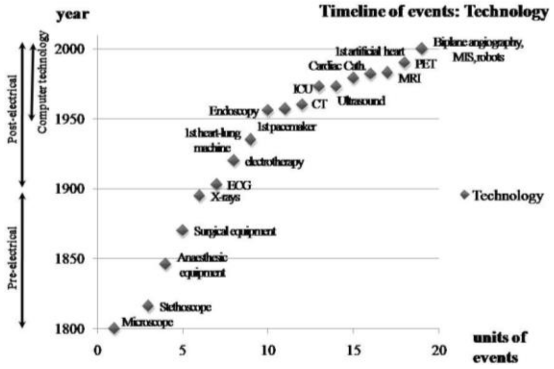
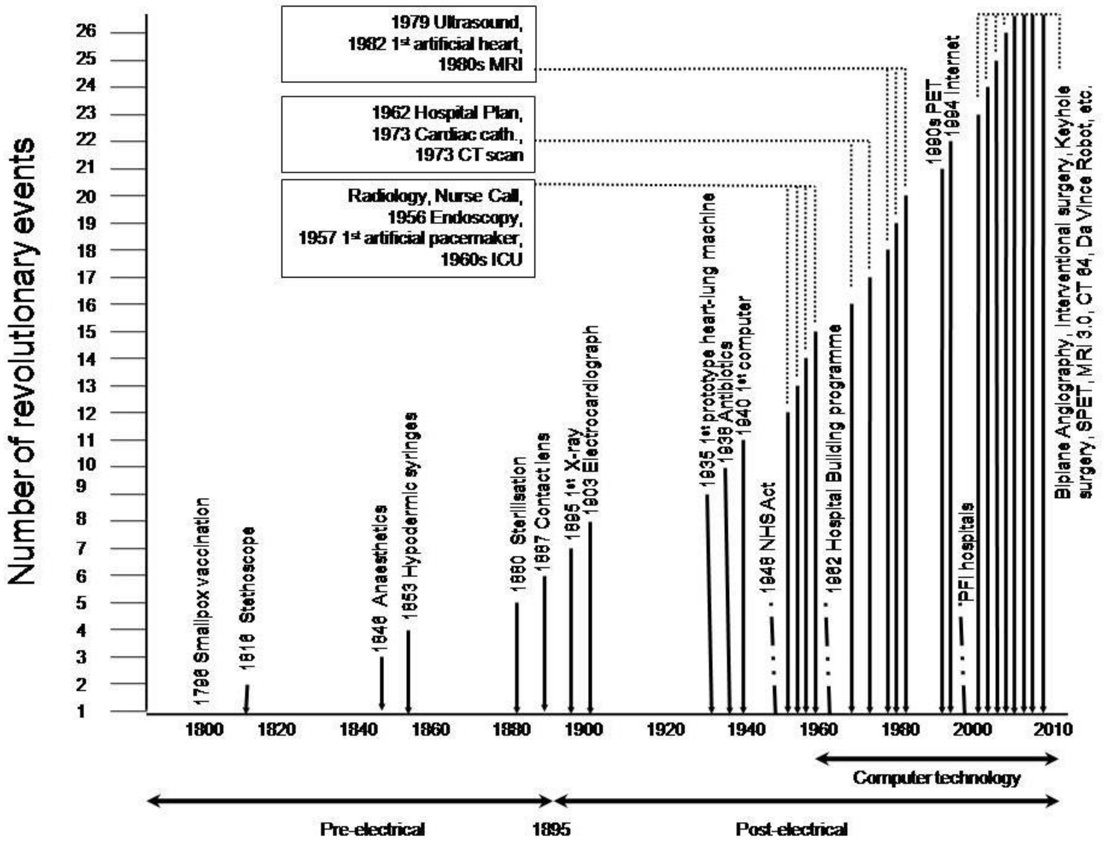


Figure 5.39 Chronological list of medical technology inventions (1800-2010).



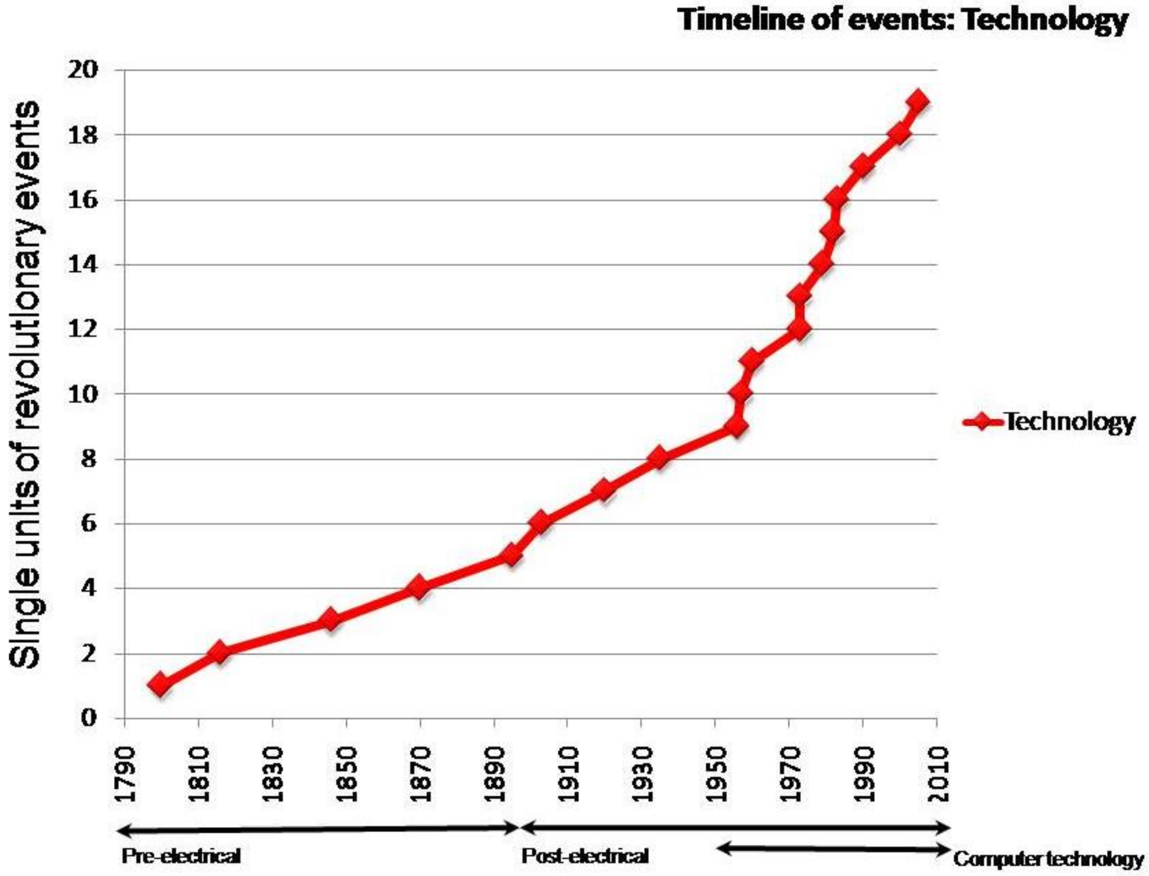


Figure 5.40 Growth rate of medical technologies post-1800.

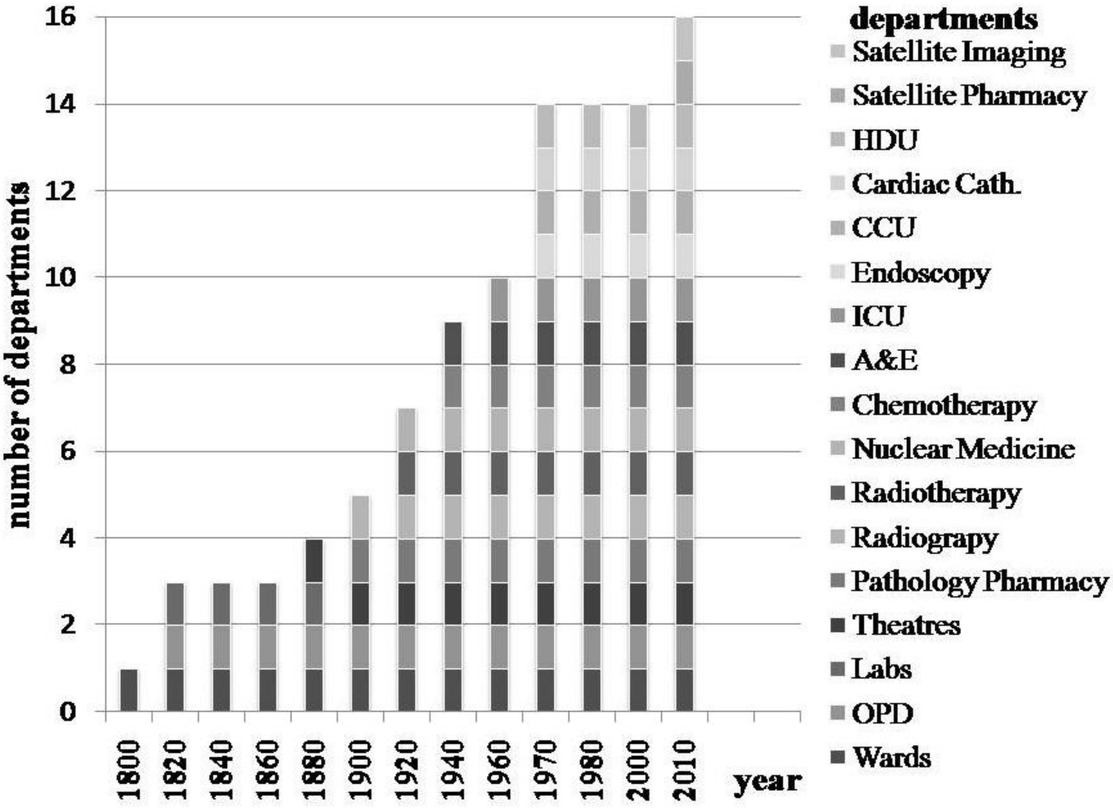


Figure 5.41 Historical mapping of hospital departmental growth (1800-2010).

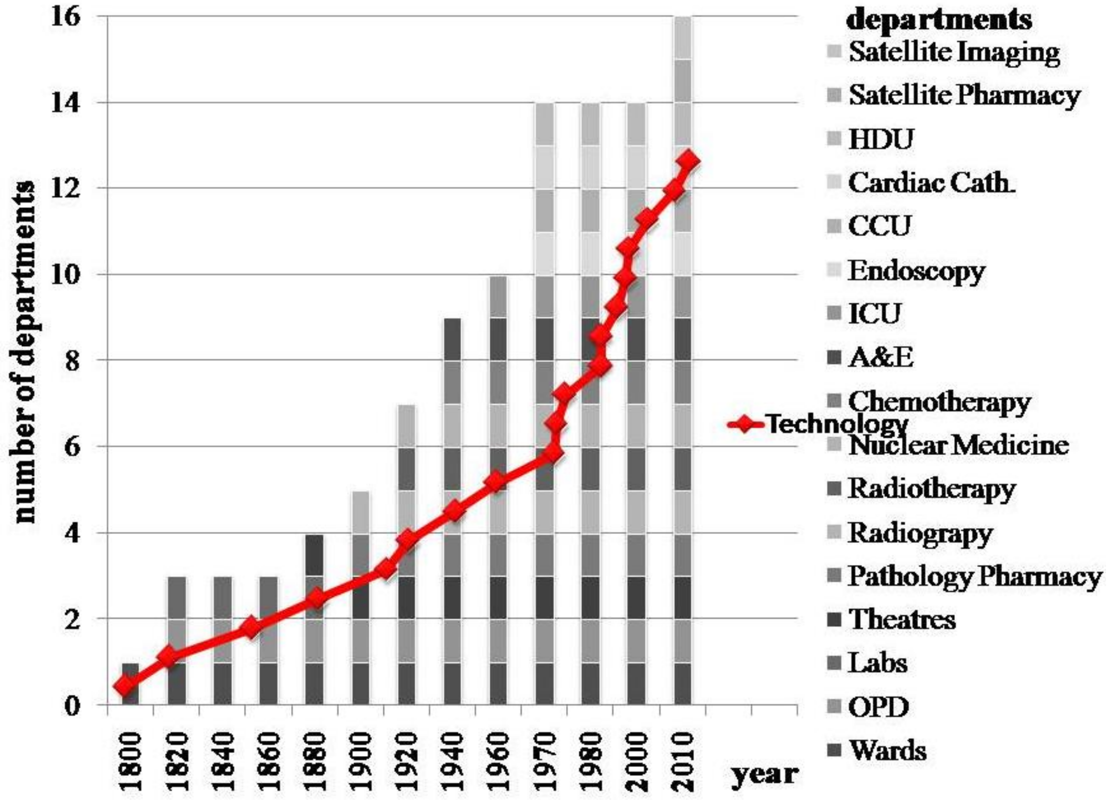


Figure 5.42 Historical growth of medical technology v hospital departments: Combined mapping of Figures 5.40-1.

5.4 Chapter Conclusion

Chapter 5 explored the development of medical technologies in British hospitals to examine and identify its affect upon past and existing hospital space. Essential lessons are drawn from the outcomes of putting new medical technologies into post-1800 hospitals, specifically, from trends that explain the rapid decline of late-20th century NHS hospitals.

The simplicity of 19th century hospital design should not to be overlooked, as architects of that time had to contend with similar existing spatial challenges. For example, in the 1880s, modestly planned hospital buildings were forced to adapt to emerging spatial issues. New OPD specialties, the rising ascent of the OT department as well as the introduction of new ‘electrical’ technologies all required innovative medical planning solutions to respond to new spatial and technological demands.

The analysis of 20th century medical technology developments raises numerous themes, such as, the constant fluctuation of medical technology sizes. In essence, a detrimental outcome unfolded from a vortex of simultaneous events that inform an understanding of the spatial failure of many late-20th century NHS hospitals. A sequence of incidents commenced with the computer revolution which instigated an abundance of new medical technologies. All new medical equipment required hospital space in existing pressurised hospital buildings. These technological changes ran concurrently with the 1970s economic crisis which forced new NHS hospitals to become smaller, cheaper buildings. The DHSS produced Harness and Nucleus model types that compromised functionality by reducing hospital spaces to 80% of HBN guidance. However, hospital design restrictions clashed with medical technology’s massive growth in numbers, size and functional area. Therefore, the outcome from putting new medical technologies into shrinking post-1960s hospital spaces was detrimental and resulted in the spatial failure of NHS hospital buildings. It is for this reason the thesis is concerned for PFI NHS hospitals as many earlier projects employed a similar Nucleus model.

‘Expansion’ area has been added to large high-tech rooms in recent PFI hospitals in recognition of a trend in recent ongoing medical technology size increases. This approach would be considered appropriate but, as this chapter demonstrates, medical technology size decreases as it progresses over time. Furthermore, Feynman states that ETs, by their nature, have to become smaller in order to develop. Both pieces of evidence lead this study to believe that spatial flexibility has been invested in PFI NHS hospitals incorrectly. For example, recent medical technologies are merging surgical and x-ray practices but PFI design briefs required no departmental adjacencies between these two medical disciplines. In most cases, these departments have been located on different floors making future developments difficult, costly and maybe impossible to renovate. In addition, the increase in mobile equipment requires new area to be distributed throughout hospitals. However, PFI schemes were designed so tightly that no spatial allowance for flexibility exists to cater for this type of hospital spatial change.

This chapter has focused on the events and developments of medical technologies in hospitals. How technological innovation impacted on the medical planning of hospitals is assessed quantitatively next and completes the thesis’ assessment of technology’s relationship with hospital space.

Chapter 6: Typological Case Studies

"Without a good plan nothing exists, all is frail and cannot endure, all is poor even under the clutter of the richest decoration"

Le Corbusier

6.0 Introduction

Chapter 6 is dedicated to achieving the thesis' second objective. This is to determine medical technology as a driver of hospital medical planning. Findings from Chapters 4 and 5 inform this chapter's exploration which examines how influential medical technology has impacted quantitatively upon past and present hospital space. The chapter begins with a description of the case study sample and its parameters. The focus of research concerns the high-tech component of NHS urban acute hospitals only. This is followed by the measurement of four London NHS hospital case studies which trace the nature of high-tech hospital space through post-1800 hospital plans. The case study sample includes the Royal London Hospital (RLH), St. Thomas', the Chelsea and Westminster, and University City London Hospital (UCLH). Each case study is examined individually before a collective spatial analysis of case study findings is presented. The chapter closes with conclusions which completes Part II's investigation of technology's relationship with hospital space

The sample of selected acute hospitals represents only 3.4% of NHS hospitals (DOH, 2007:3). Nevertheless, this particular sample contains over three hundred years of hospital spatial change. On this basis, the study's sample was considered superior to a large hospital sample with no historical background. Three main findings are revealed from this chapter's exploration:

(i) Quantitative status of past and present urban acute high-tech NHS hospital space

(ii) Identification of spatial trends that reinforce the relationship between medical technology and hospital space

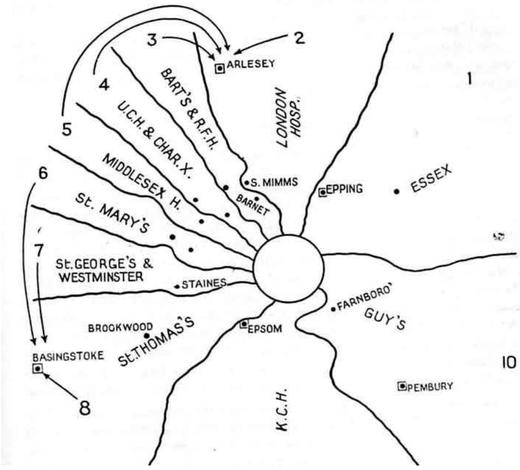
(iii) Medical technology is a dominant driver of hospital medical planning.

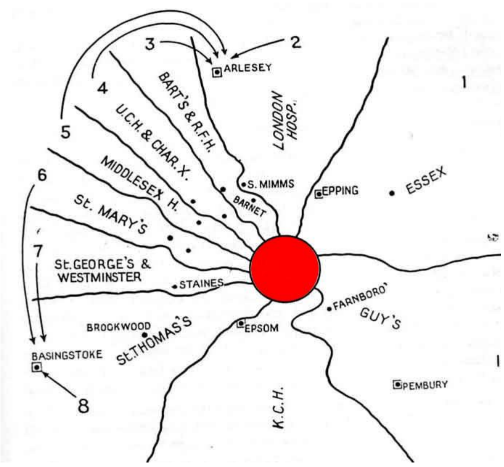
6.1 Description of case study sample

Section 3.1.1 details the specifics for choosing London as the study's sample city. This section describes the parameters employed to refine the case study sample.

(i) Geographical sample area for the London region

Healthcare services throughout the district of London are dispersed through numerous geographical regions (see Figure 6.1). Each region contains many hospitals of various disciplines but acute NHS hospitals are located upon population catchment areas specifically. Central London's acute hospitals have the additional pressure of dealing with spatial and typological restrictions in addition to greater population numbers that strain existing healthcare services. For this reason, London's Zone 1 area was chosen to represent a dense urban area with intensified health and spatial problems that challenge its city's hospital buildings with ongoing change (see Figure 6.2).





Left: Figure 6.1 Map of London healthcare regions (The Lancet, 1939:723).
Right: Figure 6.2 Zoned sample area of Figure 6.1.

(ii) Typological and sample criteria

London has a long history of 'hospitals' but as Chapters 4 and 5 reveal, medical technologies did not appear in British hospitals until the 19th century. Hence, the time scale for case study research was established as 1800-2012. Acute hospitals were selected to cover each of the four geographical extents of central London (see Figures 6.3-4).

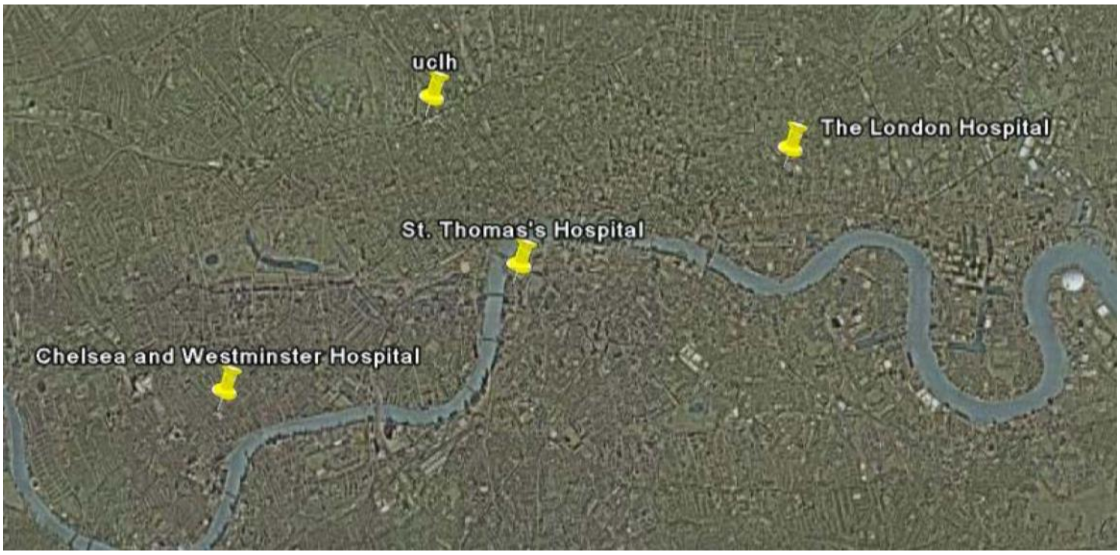
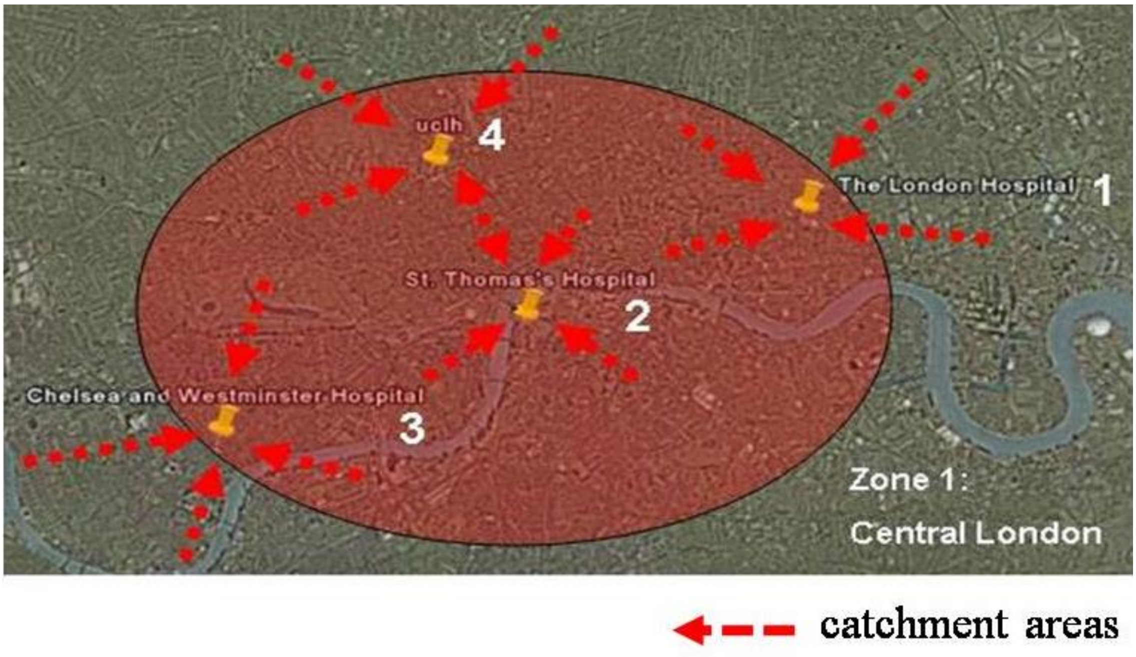


Figure 6.3 Context plan of Zone 1, A&E hospital case studies (London, UK).



1 = RLH
2 = St. Thomas'
3 = Chelsea & Westminster Hospital
4 = UCLH

Figure 6.4 Context plan showing chosen Zone 1 A&E hospitals with respect to their population catchment area (London, UK).

Seven parameters establish the case study sample (see Table 6.1). Four parameters are consistent: zone; organisation type; acuity level of care; teaching capability. This criterion establishes the following sample for measurement; central London NHS university hospitals with operational A&E departments. Three additional parameters are introduced to allow for architectural variation and the measurement of medical technology's spatial impact: site location; typology form; hospital design process. The dissimilarity between factors yielded a sample of four current hospital typology types:

(i) Campus, PFI (ii) Campus, D&B

(iii) Urban block, D&B (iv) Urban block, PFI.

A further characteristic unfolded unintentionally during the course of the case study research. Typologies became divided periodically into 19th and 20th century hospitals. These being, campus styled hospitals were designed and built initially before 1900 while urban block typologies originated post-1990. The variety in hospital typology type allows for critical examination, particularly, the sustainability of hospital campus typologies which have endured technological revolutions since 1895. Therefore, recent and past medical planning models are explored through the measurement of alternative solutions which lead to an understanding of medical technology's spatial impact upon post-1800 London's hospitals.

Case Study Hospital	**1. Zone**	**2. Location**	**3. Acuity level of care**	**4. Teaching institution**	**5. Organisation**	**6. Typological form**	**7. Financial & Design process**
RLH	1	EC1	A&E	Yes	NHS	Campus	PFI
St. Thomas'	1	SE1	A&E	Yes	NHS	Campus	D&B
Chelsea & Westminster	1	SW10	A&E	Yes	NHS	Urban block	D&B
UCLH	1	WC1	A&E	Yes	NHS	Urban block	PFI

Table 6.1 Seven parameters for each case study's hospital typology type.

6.2 Case Study No.1: Background to the RLH (Bart's & The London NHS Trust)

In 1740, The London Infirmary was established as a 30 bed voluntary hospital within horrendous non-customised rented facilities beside Moor Gate's burial grounds. Within months, high demands for patient services forced The London lnfirmary to move to larger run-down rented premises in nearby Prescott Street. Eventually, enough capital was fundraised to build a purposely-designed new hospital building. The London Infirmary relocated to the outskirts of London to its present White Chapel Mount site in 1757. It was granted a Royal charter in 1758 to become known as the RLH (Present and future of European hospitals heritage (PAPHE), 2001). This Palladian formed building, however, was forced to partly close towards the late 1700s. This outcome was driven by a widespread European financial crisis and the cost of running expensive new electrical treatments (Barry & Carruthers, 2005:73-5). Prosperity returned in the late-19th century, which resulted in the re-opening of wards and new building expansions. This is evident particularly from hospital plans between 1886-1905 (see Appendix F.1-7). By 1876, the RLH had become Britain's largest hospital but building developments became non-existent after 1905 (Barry & Carruthers, 2005:77). For example, no new facilities were built until the 1970s even though large parts of the hospital were bomb damaged during WWII.

No architectural impact is recorded from the 1948 change in hospital organisation but, as an NHS facility, the RLH continued to lead in medical technology innovation. For example, during the 1950s, pioneering orthopaedic surgery and the development of the first artificial kidney (1959) led to the opening of a new renal research unit, a genito-urinary department (1952) and new research accommodation in 1956 (NHS Trust Archives, 2008:panel8). The RLH continued to lead with cutting-edge medical technology which is represented by the hospital's current status (2010) of owning only one of two existing NHS 64-slice CT scanners (NHS Trust Archives, 2008:panel12). All new medical technologies required space as well as functional area. The RLH's space was re-planned and added to, pressurising an already compact hospital site. By 2000, the hospital's overall medical planning was inefficient and organisationally disastrous. Changes had been responded to spatially sporadically which is reflected in its plans in 2000 (see Appendix F.9).

By the 1990s, the NHS was experiencing financial difficulties that resulted in Sir Bernard Tomlinson's *Report of the Inquiry into the London Health Service* (1992). The outcome for East London and City services was the amalgamation of the RLH, the London Chest and St. Bartholomew's hospitals. All A&E services were transferred to the RLH (1995) supported by the recently established (1990) on site Helicopter Emergency Medical Service (HEMS). The RLH continued to evolve as a major urban acute facility but the hospital had fallen into major disrepair and needed to be re-built desperately. A new PFI acute hospital building was proposed as part of the *NHS 2000 Plan*. In 2012, the new £650 million PFI NHS acute hospital opened as an acute facility catering for 3,000 staff and patients per day. The new hospital contains over 110 wards (40% single-bed occupancy) and departments of medical planning complexity but remains on the same 255-year-old hospital site.

6.2.1 The RLH: Current factual content

Typology (2012): Campus style with new high rise, Urban Block.
High tech: 52,441.74sqm
Low tech: 67,521.04sqm

Area (2012): 172,098.2sqm **Floors:** 20

Departments (2012):
A&E: 5,214.68sqm
Imaging: 6,090.42sqm
Theatres: 11,103.26sqm
Pharmacy & Pathology: 15,726.24sqm
Wards: 39,684.92sqm

Technical information: 64 Slice CT scanners x 2, MRI x 2, Theatres x 26, Ultrasound, Gamma Camera & Fluoroscopy.

Dates: Opened in 2012. Architects: HOK
Six historical typologies analysed.

Vital Statistics for Barts & London NHS Trust 2006-7/2009-10 (NHS Barts, 2011):

Total number of attendances: 778,090/868,035
A&E visits: 159,862/190,216
Patients treated for emergency heart attack: 425/634
Patients operated in theatres: 26,227/NA
X-rays and scans/year: 316,866/357,629
Heart operations/procedures: 9,835/8,520
Kidneys transplanted: 70/134
Pathology tests/million: 7.5/7.7
Drug doses: 10 million/NA

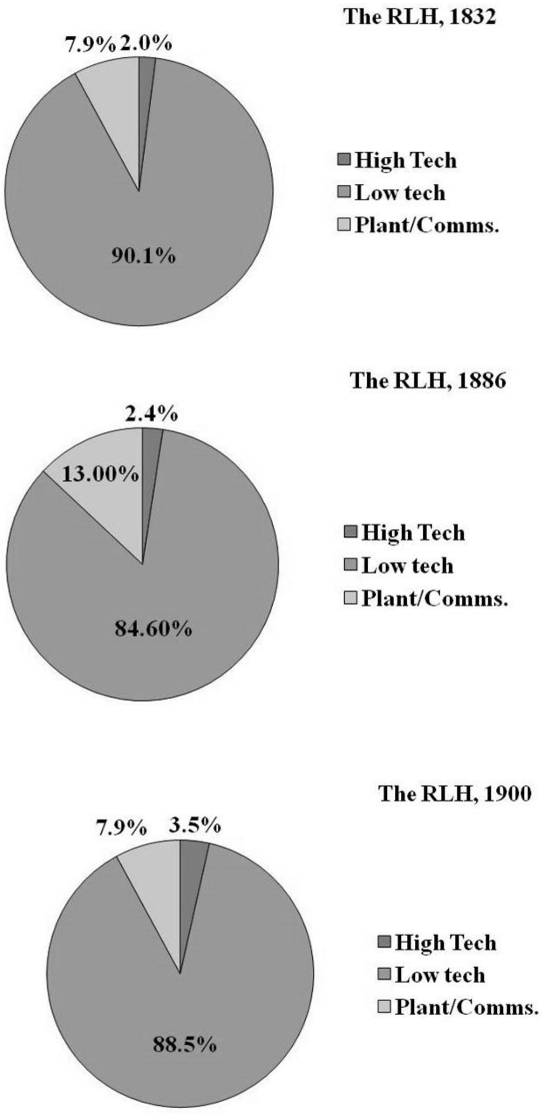
Figure 6.5 Aerial view of the RLH, London.

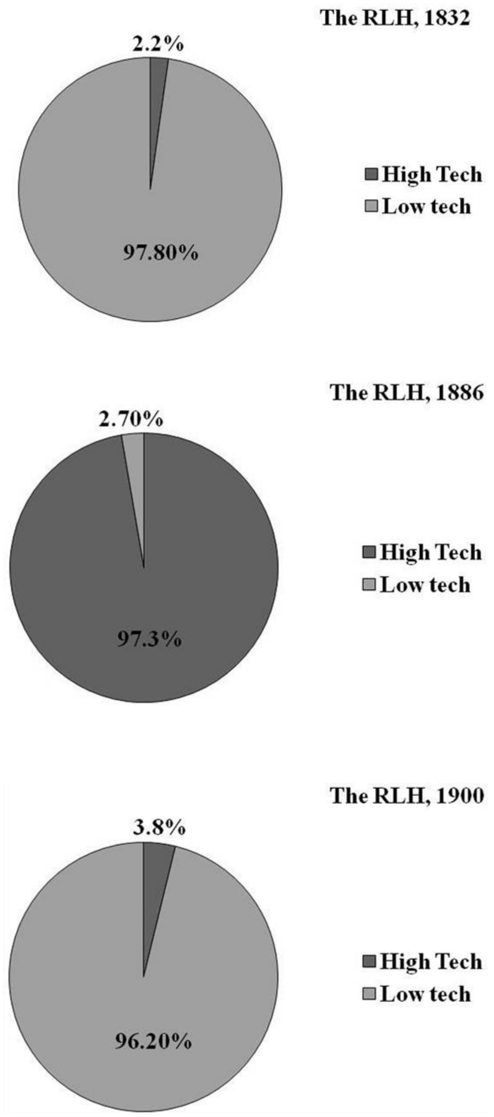
6.2.2 The RLH: Analysis of measured plans

Data measured from this case study holds over two hundred years of medical planning history. This case study maps the progression of a campus styled typology to its recent 'matchbox-on-a-muffin' urban block form. Six sets of plans were measured for the RLH. An example of each set is shown in Appendix F.1-11.

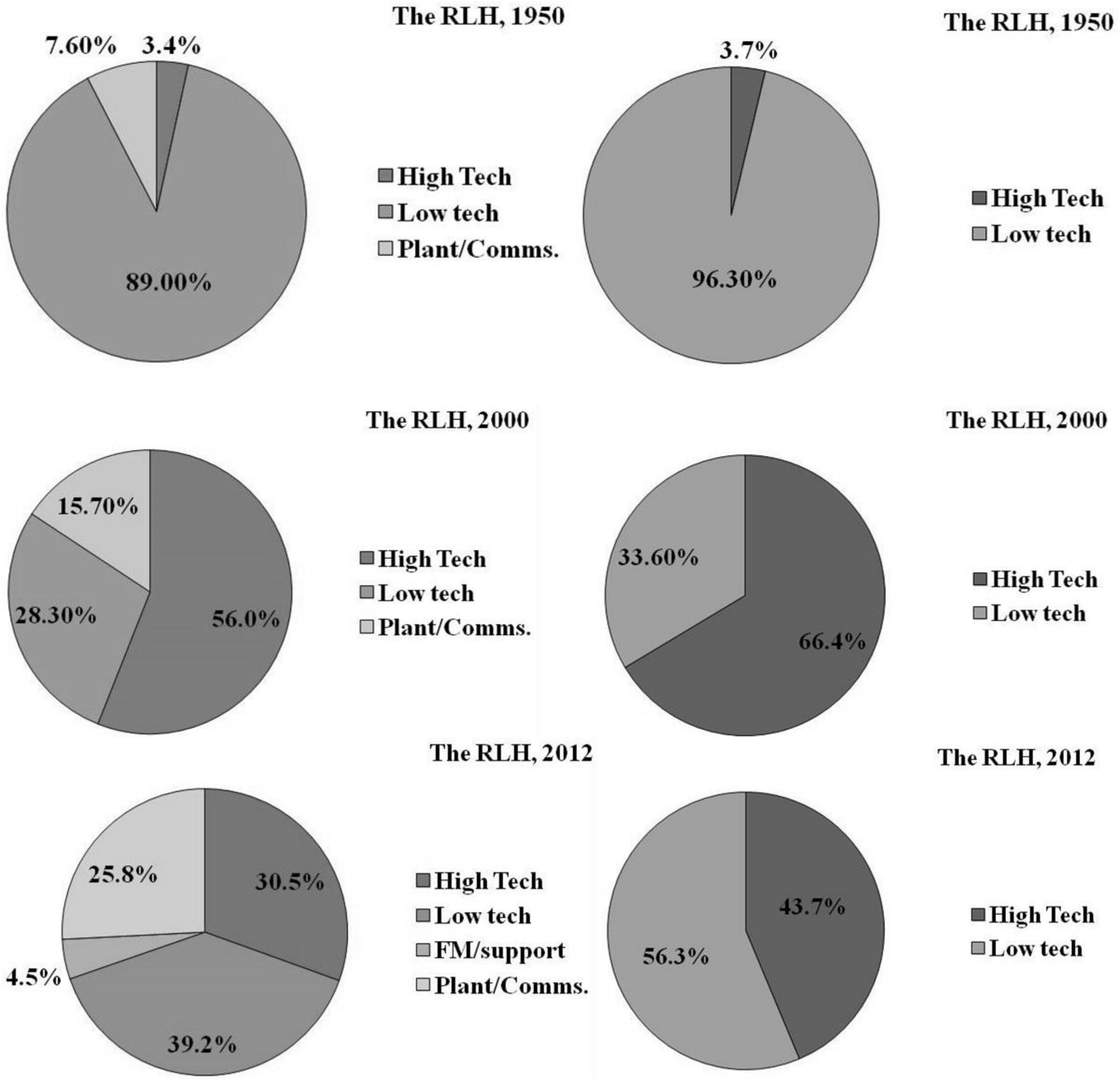
Originating as a single block form, now known as the hospital's 'Front Block', two wings were added in 1832 to form a U shaped single block. This 1832 typology is the first set of measured plans where data reveals 2.2% of the building's functional area the is of a high-tech component (excludes Plant/Comms.) (see Figure 6.6a). This statistic correlates with Chapter 4's findings that minimal technology existed in 1830s hospitals. Over the next sixty years, wings were extended and new floors were added above the existing hospital building. Quantitatively, low-tech areas still dominated (96.2%) but a slight increase (+1.6%) in high-tech components was recorded from the plans of 1900 (see Figure 6.6a). This small growth coincides with Chapter 5's post-electrical findings where changes in medical technology were starting to influence the configuration of hospital space. For example, the addition of OT rooms to the upper floors of the Front Block correlates with the growth in surgery that was driven by newly introduced surgical equipment between 1880 and 1900.

No changes are recorded between the hospital's 1900-1950 plans. However, dramatic changes occurred at the RLH post-1970. This is evident from the measured plans for 2000 which contrast drastically with the set of 1950 plans. The campus is overcrowded and fragmented but compares similarly to the growth in post-1970 medical technologies. To test if these trends are linked, data from the 2000 set of measured drawings records 66.4% of the building's functional area was dedicated to high-tech areas (see Figure 6.7a). This finding records a 62.7% increase in high-tech area between 1950-2000 and reveals a strong link between medical technology and hospital space formation. Of note is this period’s medical planning status as medical technologies and services changed. The RLH’s disjointed spatial responses led to mass inefficiencies in medical practice, finance and space. The outcome was the deterioration of the RLH which needed rebuilding at tax payers’ expense. Hence, this finding reveals; continual monitoring of a hospital’s medical planning is crucial to its sustainability.





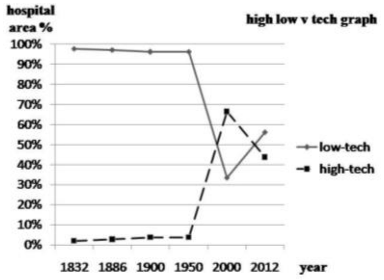
Left column: Figure 6.6 RLH: Area analysis of plans for 1832, 1886, 1900 (see Appendix F.12-9). **Right column: Figure 6.6a** RLH: Area analysis of plans for 1832, 1886, 1900 excluding Plant/Comms. area (see Appendix F.12-9).

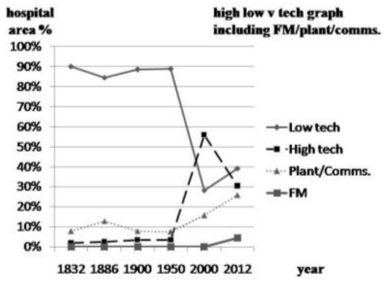


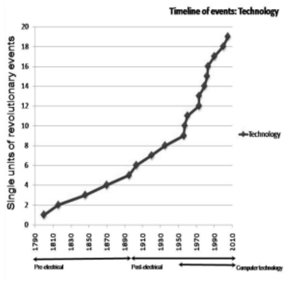
Left column: Figure 6.7 RLH: Area analysis of plans for 1950, 2000, 2010 (see Appendix F.15-9). **Right column: Figure 6.7a** RLH: Area analysis of plans for 1900, 2000, 2012 excluding Plant/Comms. area (see Appendix F.15-9).

While the new RLH opened in 2012, the hospital's medical planning was designed by the mid-2000s. This sixth set of measured drawings is of particular interest as it represents the most recent PFI NHS acute hospital in London. Notably, findings record that since 2000 the high-tech component has decreased to 43.7% of functional area (see Figure 6.7a). This indicates one of two factors: a reduction in medical technology size and use; an alternative factor. Data extracted from the plans of 2000 and 2012 show that Ward areas have increased by 29,310.01sqm (17%). This accounts for the increase in low-tech areas which contradicts current NHS policy. Alternatively, despite its decrease in proportional area, an increase in high-tech area amounts to 19,444.67sqm of extra hospital space. Therefore, a reduction in medical technology size is omitted as a factor for the recent decrease in proportional high-tech area. Instead, the thesis accredits the increase in low-tech areas to the Tower Hamlet's specific regional high demand for NHS hospital beds.

A list of historical areas is tabled in Appendix F.18-9. Graphed data from this table in Figures 6.8-8a measures the proportional rates of low-tech and high-tech areas in the RLH. Both graphs record an increased rate of high-tech area between 1832 and 2012. This data confirms quantitatively that medical technology effected hospital space at the RLH. One significant trend from this case study's findings regards the post-2000 decreased rate for high-tech space. This contradicts the ongoing growth rate for technological development identified in Chapter 5(see Figure 6.9). However, the RLH's current spatial status was identified as being driven by regional healthcare demands for a specific dense and expanding urban population. Nevertheless, this finding is a proportional rate and does not undermine the significant growth in high-tech hospital area. This ongoing trend has increased hospital space at the RLH from 508.8sqm (1832) to 52,441.74sqm (2012) and by 19,444.6sqm since 2000 alone (see Appendix F.12,17).







Left: Figure 6.8 High-tech v low-tech graph of % hospital functional areas.
Middle: Figure 6.8a High-tech v low-tech graph of %GBA (including FM areas).
Right: Figure 6.9 Figure 5.40's rate of medical technology development.

Currently, the RLH represents one of the largest PFI NHS acute hospitals which this study predicts will remain on its existing site for another 35-40 years. This is based on the hospital's campus styled typology and its ability to adapt despite ongoing revolutionary changes. For example, the introduction of its new 20 storey matchbox-on-a-muffin urban block alters the hospital's strategic medical planning orientation dramatically. Historically, this typology type is problematic for sustaining acute hospitals on tight urban sites. However, as this new building is part of a campus site, future flexibility is anticipated through the utilisation of other campus buildings and surrounding spaces (see section 8.3.1).

6.3 Case Study No.2: Background to St. Thomas' (Guy's & St. Thomas' NHS Foundation Trust)

Founded in the 12th century near the main south entry into London, the original St. Thomas' hospital formed part of the St. Mary Overie's priory (PAPHE, 2001a). This sanctuary offered a simple place for rest until its dissolution in 1546. The hospital was re-founded in 1552 at a location near London Bridge. As a Royal hospital, St. Thomas' survived the 1665 plague and Great Fire of London (1666) but the number of wealthy patrons declined afterwards. The outcome created a void in the hospital's funding regime. In response, the hospital's cemetery became a valuable source of revenue similar to the current NHS strategy for onsite hospital car parking. Many building developments followed between 1693 and the 1860s. As the hospital moved to a new location in 1871, precedent St. Thomas' typologies are not considered in this study.

In 1859, the Charing Cross Railway Line required the previous St. Thomas' hospital site. With compensation received, St. Thomas' relocated to its current Lambeth site opposite Westminster's parliament buildings. Opening in 1871 as a 600 bed hospital, St.

Thomas' was Britain's first major pavilion hospital typology. Influenced by Nightingale's design philosophy, the Victorian styled model included OT, OPD, staff accommodation and what later became known as Nightingale Wards (Richardson, 1998:7). The long narrow site disallowed for courtyards but established a simple medical planning concept: an eastern side axial corridor with interconnecting wings arranged over six floors facing the River Thames (see Appendix F.21-2). St. Thomas' became technologically innovative with both x-ray technology and electricity introduced by 1900. Only small extensions were added during the early-20th century. Thereafter, St. Thomas' suffered badly during WWII with damaged facilities remaining unrepaired for nearly twenty years.

A massive rebuilding programme transformed St. Thomas' hospital after the 1960s. Notably, MARU conducted HDR upon the efficiency of Nightingale Wards prior the hospital's redesign. As a result, the hospital's redevelopment saw the South Wing block renovated and three new 'matchbox-on-a-muffin' type clinical buildings added (see Appendix F.23,26-26a). This evolution radically altered the original uni-block typology to become a campus style hospital typology. The first 13-storey East Wing building opened in 1966 which currently houses the A&E and Cardiac Departments. The remaining two buildings followed in 1975 as a 15 storey North Wing and 7-storey Lambeth Wing. The North Wing contains a mixture of clinical activities which include Imaging, Wards, Gynaecology, Pathology and OTs. The Lambeth Wing continues to function as was intended originally: OPD, an X-Ray Department, OT, Pharmacy, Oncology and research laboratory departments. The latest addition to the campus was the Evelina Children's Hospital (2005). This £60 million 140-bed non-PFI hospital amalgamated all Guy's and St Thomas' childrens' services to one location. All buildings are linked at designated levels, similar to that at Northwick Park, allowing for the flexibility of building expansion if future spatial demands are required. However, continuous piecemeal extensions have been sandwiched between blocks over the years destroying the original principles and benefits of Nightingale's exterior green spaces.

All A&E services transferred to St. Thomas' when St. Thomas' and Guy's Hospitals merged in 1993 (PAPHE, 2001a). The effect had medical planning implications, for example, the Medical Physics department was refurbished extensively in 2002. This outcome highlights St. Thomas' spatial adaptability to change and add services without having to relocate. Now an NHS Foundation Trust, all hospital design works are undertaken by St. Thomas' Capital Estates department through D&B.

6.3.1 St. Thomas': Current factual content

Typological form:	Campus style with mixed high/low rise blocks	
	High tech:	30,372.45sqm
	Low tech:	46,902.68sqm
Area:	132,791sqm	**Floors:** 15
Departments:	A&E:	2,521.59sqm
	Imaging:	5,499.99sqm
	Theatres:	7,018.43sqm
	Pharmacy:	1,755.03sqm
	Pathology:	7,965.12sqm
	Wards:	13,677.42sqm
Technical information:	CT scanners x 3, MRI scanners x 4, Angiography/ Intervention x 5, Fluoroscopy x 3, X-ray x 16, OT x 14	
Dates:	Opened in 1871. Architects: Henry & Percival Currey/YRM. Six historical typologies analysed	

Vital Statistics for Guys and St. Thomas' NHS Trust 2008-09 (NHS Guy's, 2011):

Total number of attendances:	A&E visits:	113,000
	Eye casualty:	7,000
	Gynae. casualty:	6,000

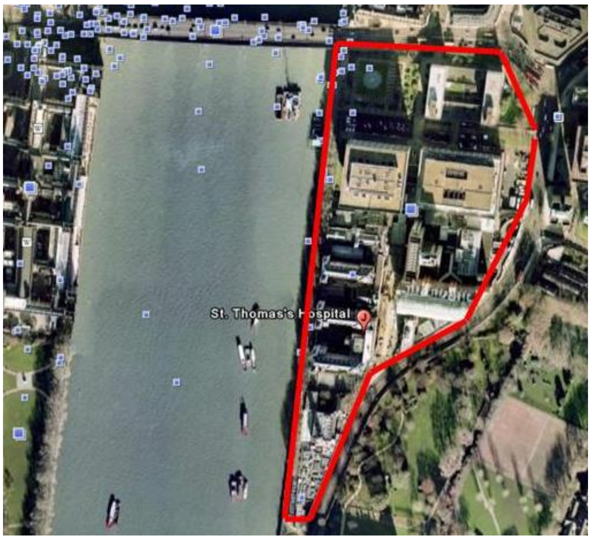


Figure 6.10 Aerial view of St. Thomas' site plan, 2010.

6.3.2 St. Thomas': Analysis of measured plans

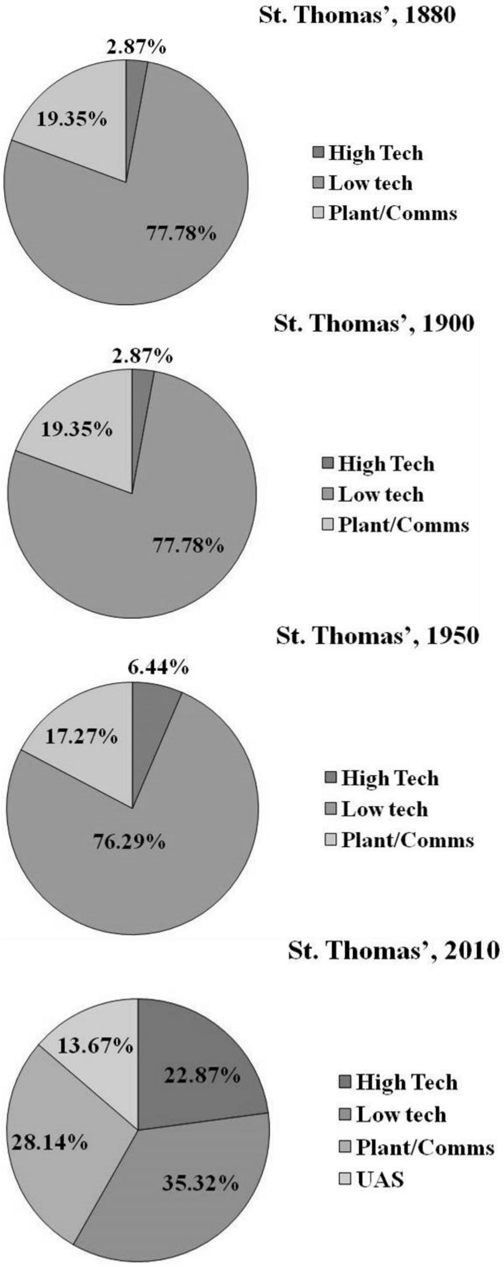
Four sets of plans are measured for St. Thomas' hospital case study (see Appendix F.20-5). Each set was measured using different methods but all case study results are standardised in Appendix F.27-32. St. Thomas' contains over 130 years of medical planning history which reveal sustainable strategies relevant to future hospital medical planning.

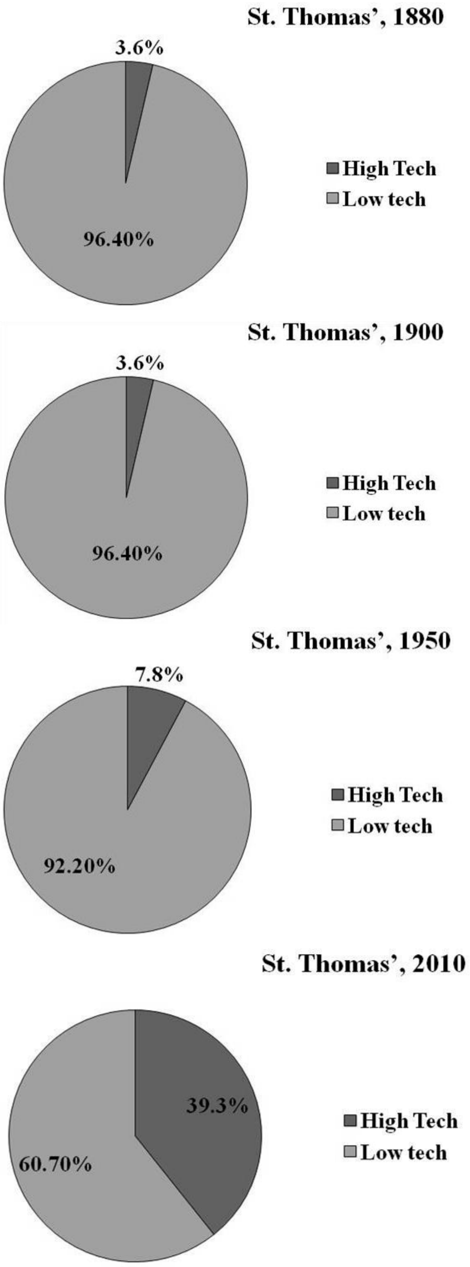
The original plans for St. Thomas' single pavilion building (1880) measure 94.4% of functional space is dedicated to low-tech areas. This re-iterates Chapter 4's findings that palliative care dominated 19th century hospital functionality. Signs of medical technology growth are indicated by the 3.6% of area dedicated to high-tech space in 1880. The plans for 1900 record the same data and remained almost unchanged in the 1950s set of plans (see Appendix F.20). While the hospital's high-tech area in 1950 was only 7.8% of functional area, this was rectified by the huge redevelopment programme constructed post-1960. Thereafter, St. Thomas' hospital typology was revolutionised from a single block typology to a campus style typology with numerous buildings that included their own Plant/Comms. systems. By 2010, high-tech areas had grown to

39.4% of functional area (see Figures 6.11a). This equates to an additional 27,839.5sqm of previously non-existent high-tech space at St. Thomas' since 1950.

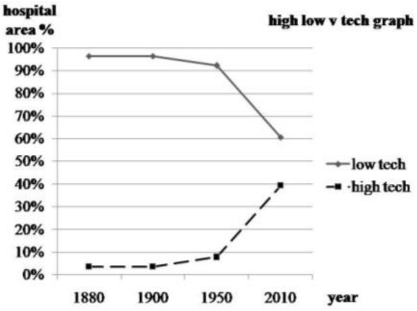
Spatial changes to St. Thomas' plans between 1880 and 2010 are graphed in Figures 6.12-12a where two major trends emerge. The first trend is the consistency between graphed area rates and previous research findings. Specifically, data maps an increase in high-tech areas which correlates with Chapter 5's growth rate in medical technology development (see Figure 6.13). Hence, this study determines that medical technology progression is linked closely to the spatial expansion of St. Thomas'. The second major trend is area distribution, of which, 13.67% of hospital area is presently set aside as un-assigned space (UAS). This generous amount of flexible space contributes to the sustainability of St. Thomas' and is achieved through a variety of UASs from large departmental areas to small 'soft-spaces'. The benefit of this policy is evident from the successful spatial reorganisation of services. For example, to accommodate for workloads transferred from Guy's hospital, Pharmacy needed to and was capable of expanding its department considerably. Alternatively, Blocks 6 and 7 house the Institute of Dermatology which was transferred recently to St. Thomas' from its previous hospital building in Soho, London. Both examples represent St. Thomas' medical planning ability to add and change services across its campus typology.

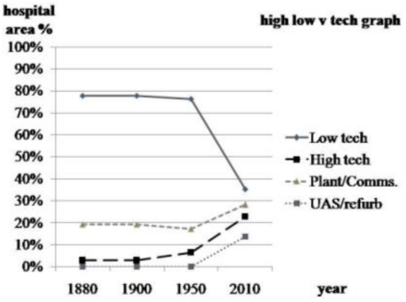
Of note, the delivery of the post-1960s masterplan was achieved only by replanning the site's surrounding infrastructure. A 1:1000 medical planning solution extended across roadways to gain extra ground surface area. This change to local architectural and road topographies was a successful strategy to resolving St. Thomas' long-term medical planning issues, which this study advocates, is necessary for sustaining urban acute hospitals.

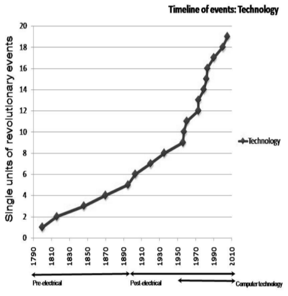




Left column: Figure 6.11 St. Thomas': Area analysis of plans for 1880, 1900, 1950, 2010 (see Appendix F.27-32).**Right column: Figure 6.11a** St. Thomas': Area analysis of plans for 1880, 1900, 1950, 2010 ex. Plant/Comms. area (see Appendix F.27-32).







Left: Figure 6.12 High-tech v low-tech graph of % hospital areas.
Middle: Figure 6.12a High-tech v low-tech graph of % GBA including UAS.
Right: Figure 6.13 Figure 5.40's rate of medical technology development.

6.4 Case Study No.3: Background to the Chelsea and Westminster Hospital (Chelsea &Westminster Hospital NHS Foundation Trust).

As the first voluntary hospital, the Westminster Infirmary was founded (1719) as a 10 bed facility in a small house in Petty France, Pimlico (NHS Chelsea & Westminster, 2009). Within five years, the infirmary had relocated twice before settling at a rented Pimlico address. The hospital remained in the same location for over a century where innovative medical practices took place, such as, stone extractions and cataract treatments. In 1834, its first purpose-built hospital opened at The Sanctuary opposite Westminster Abbey. This Westminster Infirmary remained operational as a single block typology for 110 years. Extensive refurbishments were undertaken in 1924. Nevertheless, the necessity for a new hospital was required to cater for spatial and technological changes. Demands included new rooms for radiography and internal bathrooms (Barry & Carruthers, 2005:60,64). Inflexible site constraints forced the hospital to relocate to a new site at St. John's Gardens, Westminster (1939). Another single block typology was adopted, this time surviving for 54 years only. Thereafter, the hospital was relocated to its current site at the Fulham Road, London (see Appendix F.33).

Founded in Hampstead in 1903, a new purpose-built hospital for the Infant's Hospital was built in London's Vincent Square (1907) (Barry & Carruthers, 2005:261). As a single urban type block hospital, which amalgamated with the Westminster Hospital in 1946, the hospital building remained unchanged until it moved into the current Chelsea and Westminster Hospital. Little is mentioned of West London, St Mary Abbots and St Stephen's typologies only that all were established during the 19th century and developed medical specialities, such as, maternity at West London Hospital.

In 1993, five London hospitals amalgamated to form the new Chelsea and Westminster hospital. All services, staff and equipment were transferred from the Westminster Hospital, the Westminster Children's Hospital, St Mary Abbots Hospital (Kensington), St Stephen's Hospital (Chelsea) and the West London Hospital in Hammersmith. Presently, the existing Chelsea and Westminster hospital offers an urgent-acute service as well as oncology, women’s and children’s services in a building built under a D&B process. The Chelsea and Westminster represents one of the last hospitals built prior to the PFI programme but does not reflect a Nucleus form type typology. The hospital is an urban block typology with deep-space medical planning which surrounds the first deep-plan atrium with evaporating roof that complies with the building’s fire strategy[1] (see Appendix F.34).

6.4.1 Chelsea and Westminster: Current factual content

Typological form:	Urban Block, high rise	
	High tech:	28,522.40sqm
	Low tech:	24,155.18sqm
Area:	77,280.62sqm	**Floors:** 8
Departments:	A&E:	838.16sqm
	Imaging:	963.64sqm
	Theatres:	2,807.40sqm
	Pharmacy:	1,895.20sqm
	Pathology:	4,675.12sqm
	Wards:	15,868.84sqm
Technical information:	Services include: CT/MRI/Angiography/Fluoroscopy/ X-ray/Ultrasound/Nuclear Medicine/Dexa scanner	
Dates:	Newly built in 1993. Architects: Sheppard Robson One set of drawings analysed.	

Vital Statistics for Chelsea and Westminster NHS Trust 2008-9 (NHS C&W, 2009a):

Total number of attendances:	A&E visits:	90,000
	A&E paediatric visits:	30,000

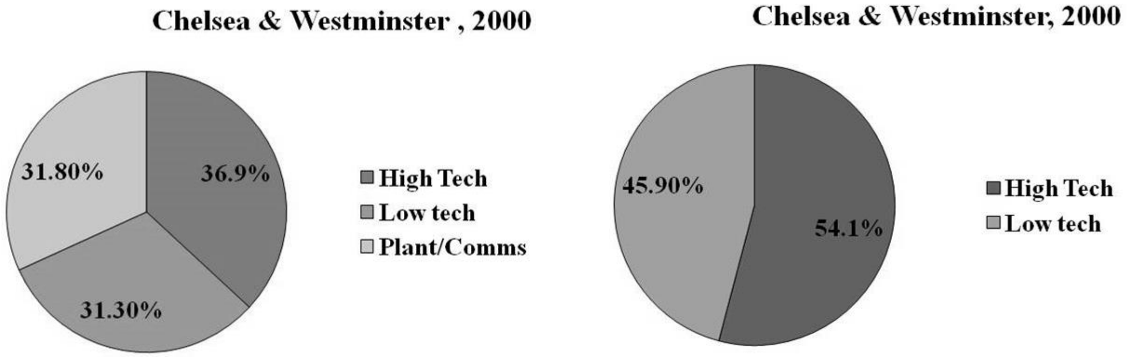
---

[1] At high temperatures, the roof evaporates allowing smoke to escape through the atrium.

Figure 6.14 Aerial view of Chelsea and Westminster's hospital site plan.

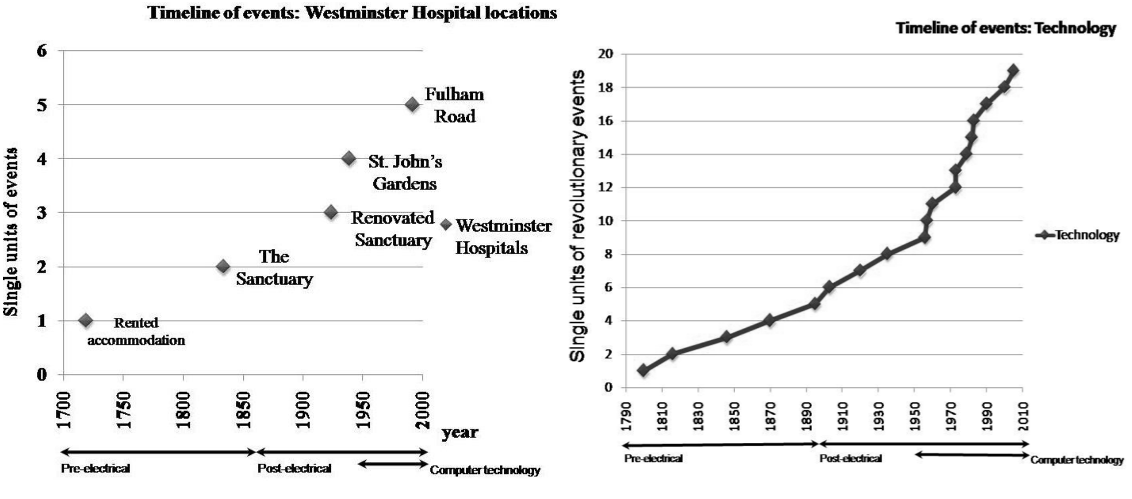
6.4.2 Chelsea & Westminster: Analysis of measured plans

No typology changes are recorded since the opening of the Chelsea and Westminster in 1992 (see Appendix F.38). Therefore, only one set of plans was measured for this hospital's case study.



Left: Figure 6.15 Chelsea and Westminster: Area analysis of plans for 2010 (see Appendix F.35-7). **Right: Figure 6.15a** Chelsea and Westminster: Area analysis of plans 2010 excluding Plant/Comms. area (see Appendix F.35-7).

No historical plans are measured to compare the rates of high-tech areas against medical technology growth. Instead, an analysis of the Chelsea and Westminster's historical events is assessed in Figure 6.16. The hospital's chequered past for relocating equally unlocks valuable information. Figure 6.16's graph identifies hospital relocations coincided with the growth rate of medical technologies in Figure 6.17. On this basis, the study determines that medical technology strongly influenced the failed success of previous Chelsea and Westminster hospital medical planning. Furthermore, to contextualise the impact of current medical technologies, 28,522.40sqm of high-tech space presently drives the configuration of Chelsea and Westminster's typology.



Left: Figure 6.16 Timeline of Westminster Hospital locations.
Right: Figure 6.17 Figure 5.40's rate of medical technology development.

From data recorded in Appendix F.35, 54.1% of functional area is dedicated to high-tech areas in the existing Chelsea and Westminster hospital (see Figure 6.15-15a). This finding is a higher rate for high-tech areas than previous case study results but reflects 1990s healthcare policy to reduce acute hospital bed numbers. Therefore, in assessing all three hospital case studies, a spatial finding of note indicates; hospital bed numbers have increased since 2000 in newly built London hospitals in response to urban population growth.

A major concern to this study is the hospital typology's density upon the Fulham Road site. No ground floor surface area is available for construction raising questions about the hospital's future expansion and longevity. Unlike St. Thomas' where a large amount of UAS maintains the hospital's flexibility, no UAS was recorded in the Chelsea and Westminster's deep-space planned, urban block typology. Hence, this study has reservations for the future development of the Chelsea and Westminster hospital as without a 1:1000 masterplan strategy the hospital's sustainability will be impeded.

6.5 Case Study No.4: Background to UCLH (University College London's Hospitals NHS Foundation Trust).

In 1834, the London University opened the 'North London hospital' on Gower Street. By 1841, and again in 1846, extra wings had been added to this purpose-built 130 bed general hospital (Barry & Carruthers, 2005:127). Throughout the late-19th century, bed closures and general building decay resulted from a lack of funding. A large donation allowed for the whole hospital to be rebuilt between 1897 and 1906 on a site opposite the existing 19th century single block hospital. The new hospital adapted the principles of the pavilion typology but modifications were necessary to respond to a very restrictive site (see Appendix F.41). The strategic medical planning concept consisted of a four storey base building with a distinct cross-shaped ward block on top which resembles the later 'matchbox-on-a-muffin' concept (PAPHE, 2001b). This typology's design was not only driven by site, its distinct model of care arranged clusters of beds around a central point of patient observation that created a smaller cross-shaped ward template (Richardson, 1998:36). Expansion was minimal over the 20th century with the addition of an obstetrics building in 1927 and 1937. By the 1990s, a new facility was needed desperately which resulted in a new UCLH opening in 2005 (Richardson, 1998:130). The previous 1906 typology accommodates UCL's research laboratories presently while UCLH has moved to a new site on Euston Road.

The current UCLH was opened at a cost of £422 million as a PFI NHS facility that is contracted for 40 years. The 76,249sqm of new hospital space provides for 10% more in-patients and 14% more outpatients which contradicts current DOH healthcare policy (DOH, 2007:6-8). Conceptually, a ‘match-box-on-a-muffin’ type typology, the strategic medical planning for UCLH is divided into two distinct forms: a tower (3 basements, 17 upper floors); a podium (2 basements, five upper floors) (see Appendix F.41a). Housing fourteen OT rooms, six radiotherapy bunkers, two Cath. Labs. and thirty-eight imaging rooms, UCLH typically represents current high-tech urban acute PFI NHS hospitals (Hospital Management.net, 2011).

6.5.1 UCLH: Current factual content

Typological form:	Urban Block, high rise	
	High tech:	27,688.10sqm
	Low tech:	9,399.50sqm
Area:	76,249sqm	**Floors:** 20
Departments:	A&E:	6,085.10sqm
	Imaging:	1,496.90sqm
	Theatres:	2,198.00sqm
	Pharmacy:	579.10sqm
	Pathology:	Not part of PFI
	Wards:	4,779.00sqm
Technical information:	CT scanners x 3, 1.5 Telsa MRI scanners x 4, Angiography/Intervention x 5, Fluoroscopy x 3, X-ray x 16, OT x 12 (220 sessions/week), Day OT x 2, Hybrid OT x 2, Nuclear Med. x1, Dexa x 1	
Dates:	Opened in 2005. Architects: Llewellyn-Davies One set of plans analysed by SOA.	

Vital Statistics for UCLH 2009-10 (NHS UCLH, 2011):

Total number of attendances:	A&E visits:	100,000
	Operations in OT:	22,066
	Day Cases in Day OT:	5,243

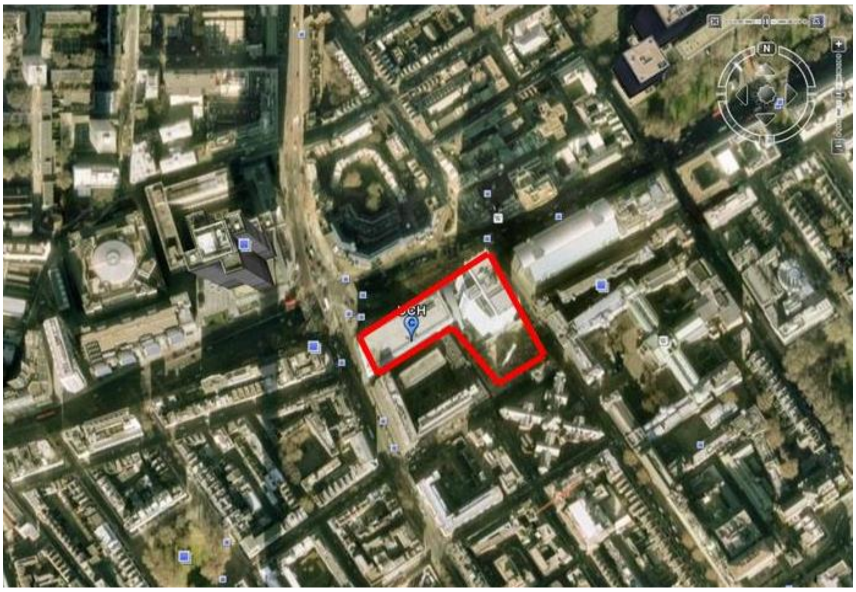


Figure 6.18 Aerial view of UCLH site plan.

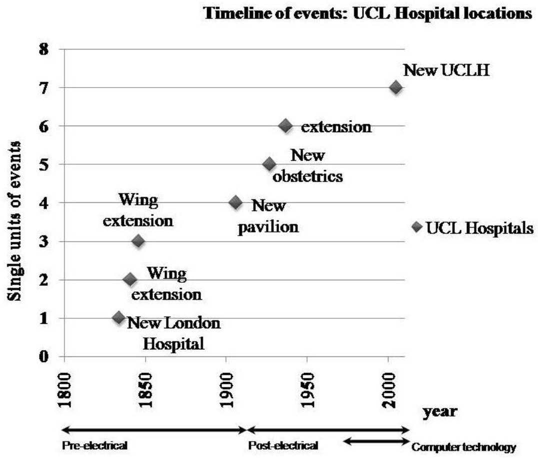
6.5.2 UCLH: Analysis of measured plans

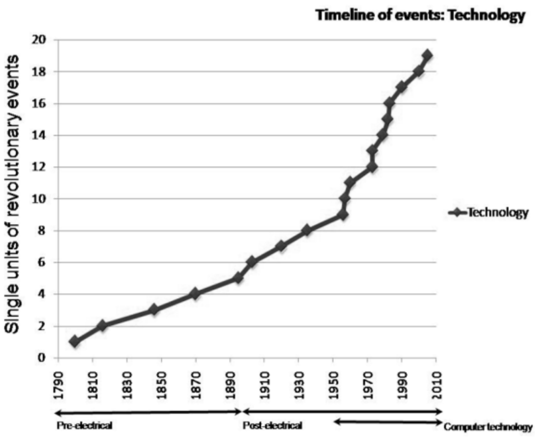
One set of plans (2010) was measured for UCLH's case study. Examples of its typology are shown in Appendix F.39. No departmental changes are considered in this evaluation even though high-tech areas were being replanned by 2011.

With regards to measuring the impact of medical technology on UCLH space, the same method was employed as the Chelsea and Westminster's mapping of historical relocations. Graphed in Figures 6.19-20, similar progressions are observed between 1834 and 2010. Bursts of architectural activity followed technological developments implying medical technology directly impacted on UCLH's hospital space. Furthermore, plans to rebuild the hospital by the 1990s lead this study to determine; the previous building struggled to cope spatially from post-1970s medical technology revolutions.

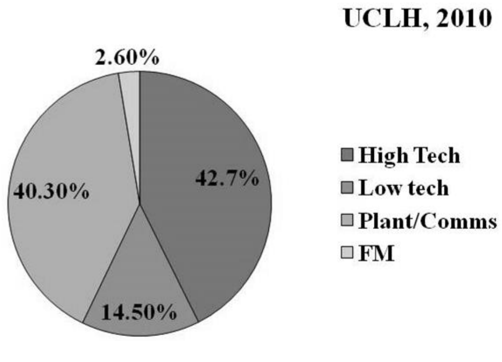
Data measured from the UCLH typology is analysed in Figures 6.21-21a (see Appendix F.42-5). High-tech functional area is recorded as 74.7%. Of note is the absence of

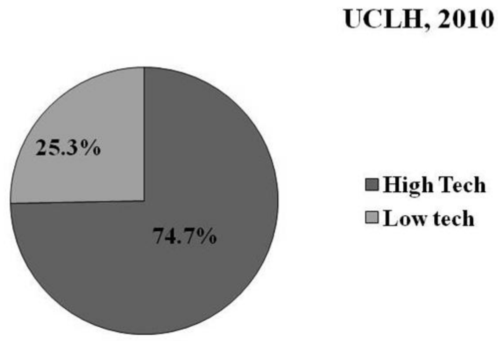
Pathology which is located off-site nearby. If included, Pathology would have increased the high-tech area rate but does not affect the hospital’s spatial status; high-tech functional area dominates the composition of current UCLH space. This finding reveals two inter-related spatial issues of importance. The first spatial issue is the high proportion of high-tech functional area. This finding identifies the current dominant status of medical technology in UCLH which underpins this study’s expressed concern for this hospital’s future. This concern is underpinned by a second issue which is the premature invalidity of precedent UCLH urban block typologies. These hospitals became void from technological innovation which was driven by a far lower proportion of high-tech functional space. Therefore, thesis concerns are founded upon UCLH’s high proportion of dedicated high-tech space and anticipations for major spatial change.





Left: Figure 6.19 Timeline of UCL Hospital locations.
Right: Figure 6.20 Figure 5.40’s rate of medical technology development.





Left: Figure 6.21 UCLH: Area analysis of plans for 2010 (see Appendix F.42-5).
Right: Figure 6.21a UCLH: Area analysis of plans 2010 excluding Plant/Communications area (see Appendix F.42-5).

Overall, UCLH hospitals were rebuilt three times over the past 170 years. Each new building was relocated due to an absence of spatial adaptability. New sites were found nearby precedent hospital buildings to become part of UCL's expanding university grounds. Within the current campus, UCLH exists as a dense urban block but no scope exists for future expansion as its footprint covers its hospital site completely. With a history of relocations that resulted from spatial failure of urban block typologies, this study considers UCLH's future to be one of relocation unless a 1:1000 medical planning solution is employed for future sustainability.

6.6 Analysis of hospital case studies

A combined spatial analysis completes Chapter 6's hospital case study investigation.

All case study high-tech areas are graphed in Figure 6.22. Data identifies three trends:

(i) 1832-1950: A clustered pattern exists of 2-3%. This consistent data maps the minimal use of medical technology in 19th and early-20th century hospitals

(ii) 1950-2000: Rates are spaced randomly between 25% and 66.4%. Results are inconclusive but all case studies experienced spatial growth in high-tech areas

(iii) 2010/12: While a scattered range of rates is recorded (35-74.4%), all rates increased immensely from a 3% average in 1950.

The study concludes from quantitative findings that high-tech hospital space has increased greatly since 1950 which correlates with Chapter 5's measured growth rate for medical technology progression. This simultaneous progression demonstrates an interconnected relationship exists between technological innovation and hospital spatial change. However, a standard growth rate for hospital space was determined inconclusive based on the inconsistencies amongst hospital age, GBA and hospital typology type.

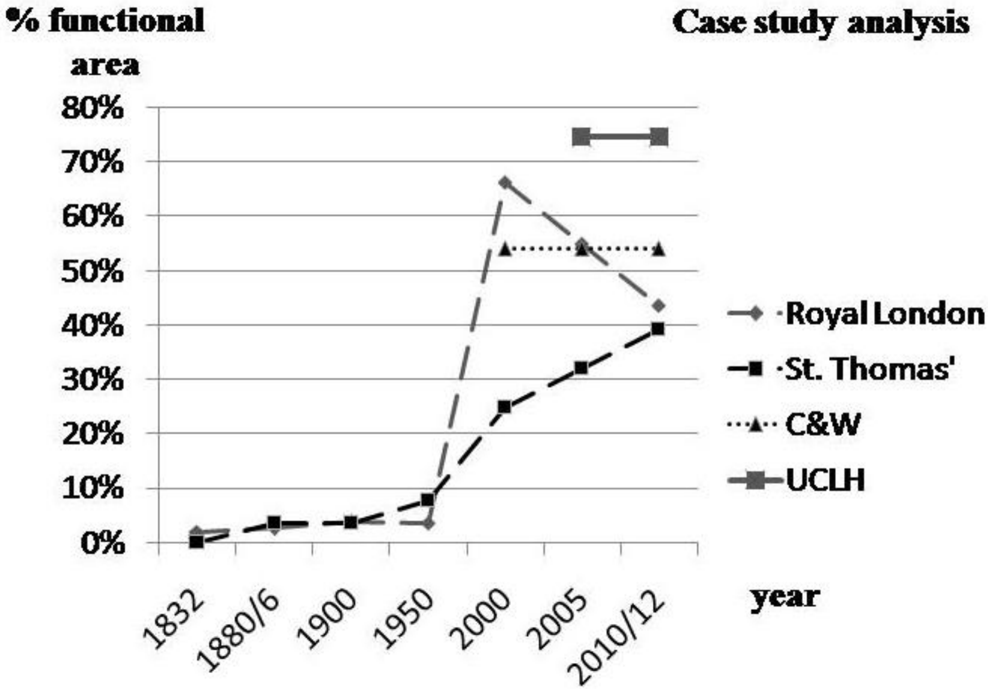
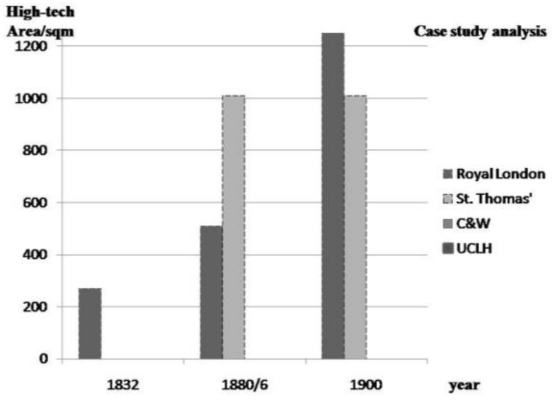
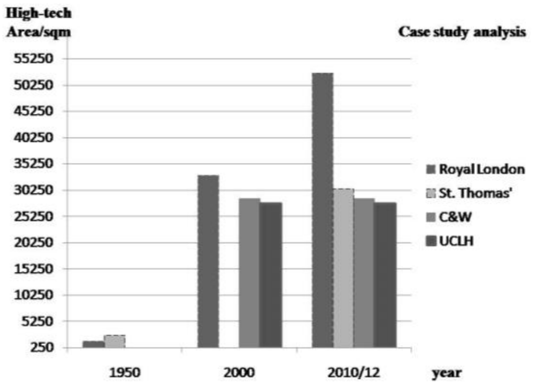


Figure 6.22 Development rates of case study high-tech areas (1832-2010/12).





Left: Figure 6.23 Area/sqm for case studies high-tech areas (1832-1900).
Right: Figure 6.23a Area/sqm for case studies high-tech areas (1950-2010/12).

A second quantitative analysis examines the relationship between all case studies' high-tech areas (see Figure 6.23-23a). Interestingly, despite variable GBAs for each measured typology, a clustered pattern emerged for post-1900 high-tech areas. For example, the average high-tech space was 1,100sqm in 1950 while current high-tech areas average between 25-30,000sqm (excluding the RLH which accounts for the UK's largest NHS hospital). On average, an extra 21,900sqm of high-tech space has been added to London's acute hospitals since 1950 - the same period when hospital medical planning changed radically and became complex. Furthermore, this data quantifies the spatial challenges that NHS hospitals faced in the later 20th century. On this basis, this study determines; medical technology has been and remains a dominant driver of NHS hospital space.

	Case study 1: RLH	**Case study 2:** St. Thomas’	**Case study 3:** Chelsea & Westminster	**Case study 4:** UCLH
Organisation & process	Voluntary/ PFI	Royal/D&B	Voluntary/D&B	General/PFI
Typology type:				
previous	Single block	Single pavilion Block	Single block	Pavilion, urban block
current	Campus with urban block	Campus with urban blocks	Urban block	Urban block
1840	Y	X	X	X/Rebuilt
1870	Y	Y	Y	Y
1900	Y	Y	Y	X/Rebuilt
1950	Y	Y	X/Rebuilt	Y
2000/10	Y	Y/Rebuilt on same site	X/Rebuilt on new site	X/Rebuilt on new site
Future	Yes/maybe	Yes	No	Maybe

Y = on existing site X = on previous site

Table 6.2 Time line for case studies.

A final analysis charts case study data in Table 6.2 where recurring issues emerge to form three significant trends.

(i) Organisation, as previously addressed, drives the opening and closure of hospitals. From this chapter’s exploration, both organisation and building processes emerge as not implicating on hospital space formation. Of interest to this study is the impact differences between PFI v D&B. As findings proved inconclusive within this study, POE of PFI hospitals is required to measure this relationship.

(ii) The relocation of hospitals was acknowledged as relating to the spatial failure of urban blocks forms. For example, the Chelsea and Westminster was rebuilt three times during the 20th century alone. This is an alarming rate for relocating and rebuilding a hospital. Similarly, UCLH, as a single block typology, relocated on numerous occasions but its 1906 typology seemed to survive the 20th century technological revolution. Unfortunately, plans were unavailable to examine how this hospital coped with post-1960s change but considering UCLH was one of first PFI hospitals, this study arrives at one conclusion; UCLH desperately needed to be rebuilt from its inability to spatially function, expand and adapt. Extraordinarily, the same medical planning model was adopted for the latest UCLH building. This approach is considered unsustainable drawing from the hospital's track record of failed single block typologies and its building's current high amount of high-tech area. As all of these hospitals were urban block typologies, this study determines; urban block typologies are inappropriate for creating sustainable urban acute hospitals on restrictive sites.

(iii) The sustainability of hospitals is acknowledged to be delivered through campus styled typologies. Two medical planning principles underpin the success of this typology type. The first principle is the incorporation of UAS which provides flexible space during on-going developments. The thesis identifies both St. Thomas' and RLH's use of UAS as driving their success for over 120 years. This finding instigates another concern for PFI hospitals as most were built exactly to or under the size of briefed areas. As a result, the thesis is not confident about the durability of PFI urban blocks should identified trends in this chapter be adhered to strictly. For example, the new twenty-storey 'matchbox-on-a-muffin' RLH's urban block raises concern is as this new addition alters the hospital's strategic medical planning model. However, as the PFI block can utilise surrounding campus space, this building's sustained future can be directed as part of a campus wide strategy. This strategy represents, what the thesis believes is, a second and essential medical planning principle; the necessary employment of 1:1000 medical planning solutions. The success of this principle was shown to be fundamental in creating St. Thomas' recent sustainability. Hence, the thesis' anticipation for neither the Chelsea and Westminster or UCLH to survive on their existing hospital sites can be avoided by incorporating innovative medical planning solutions at the urban level to reverse their urban block typology's adaptability status.

6.7 Chapter conclusion

Chapter 6 examined medical technology's influence upon hospital medical planning. Quantitative assessments revealed: the rate of high-tech hospital space in post-1800 plans has grown immensely; the composition of post-1950 hospital space has been altered greatly as relationships between medical technologies and space have evolved. Contextually, growth was represented by thousands of sqm of new high-tech hospital space but the outcome led to a critical revolution in medical planning history. The accumulation of new high-tech space created a new 'D&T' component. Furthermore, as high-tech space increased, medical planning relationships multiplied which required whole new ways of medical planning. The spatial outcome was manifested architecturally in the form of new hospital typologies, notably, the matchbox-on-a-muffin type model. For some NHS hospitals, new medical planning challenges were so vast and detrimental, that existing hospitals became obsolete where the only option available was relocation and rebuilding. Collectively, the analysis of findings leads the thesis to confirm; medical technology is a dominant driver of hospital medical planning.

This chapter's quantitative findings support Chapter 4 and 5's evidence while revealing relevant medical planning principles for future hospital design. Of note, the computer technology revolution greatly affected late-20th century hospitals that led to pressurised hospital space and the need for new medical planning models. This impact of medical technology continues as experienced within current PFI NHS hospitals. At present, financial problems are forcing NHS services to be consolidated at fewer locations. This strategy escalates spatial pressures on existing PFI NHS hospitals. One example, results from the Barts and the London Trust struggling to pay their NHS mortgages (Randhawa, 2011:10). Consequently, services, such as A&E, were transferred from non-PFI to their PFI NHS hospitals. The outcome is the demand for extra medical technologies and the requirement for more hospital space. However, such changes were unaccounted for spatially within PFI hospital designs. Other medical planning trends identified in this study are liable to continue or re-appear. For example, a spatial inability to respond to technological change is identified as an ongoing trend for urban block spatial failure. This medical planning trend is of serious concern as this chapter's findings reveal, the current presence of high-tech space has never been so extensive in NHS hospitals. Hence, knowledge revealed from the study is critical for understanding the major spatial and medical planning problems that face future urban acute NHS hospitals in order to plan for change.

To conclude Phase II's exploration of hospital space and technology, objectives one and two have been explored and met. Two conclusions are drawn:

(i) A relationship does exist between medical technology and hospital space

(ii) Medical technology is a dominant driver of hospital medical planning.

Based on these findings, and the rapid approach of ET realisation, it is necessary to spatially prepare for what is anticipated to be a radical medical revolution. Le Corbusier argues, *without a good plan nothing exists.* The impact of technological change on future hospital space is explored next in Part III to identify key principles for creating future medical planning and spatial solutions.

Chapter 7: Exploring the future - medical ETs and practice

"Sometime in the next thirty years, very quietly one day we will cease to be the brightest things on earth"

James McAlear[1]

---

[1] President of Gentronix Laboratories (Kaku, 1998:70).

7.0 Introduction

Phase III of the research is dedicated to understanding anticipated medical ETs in a bid to visualise future urban acute NHS hospital space. Chapter 7 is focused on achieving the third thesis objective. This is to investigate the impact of predicted medical ETs on future UAT treatments and associated spaces. The chapter begins by defining ET principles, the factors driving technology success and the degree of certainty for ET. This is followed by a brief outline of ET's current position within healthcare before three prevalent medical ETs are examined. The exploration of biotechnology, robotics and cyborgization is underpinned by two pertinent questions: (i) how will medical ETs change medical practice?; (ii) what trends emerge to assist with visioning the future design of hospital space? Thereafter, chapter findings are discussed collectively with respect to their spatial implications. Chapter 7 closes with key trends identified that underpin Chapter 8's scenario creation.

As per *Moore's Law*, existing computer technology is at the commencement of an immense new technological revolution (see Appendix G.1). Technology progression is anticipated to be so great that James McAlear argues *we will cease to be the brightest things on earth* in the not so distant future. Part of this technological revolution concerns changes to medical practice. This chapter's main focus is to understand the differences between current and future medical technologies. ET theoretical and technical information is documented extensively within a plethora of post-1960s scientific works. Delivery of anticipated new medical treatments is not so evident from literature. Consequently, medical planners are challenged 'to conceive and render spaces that can accommodate these revolutions' (Porter O'Grady, 2007: 17). Undoubtedly, the future cannot be predicted but optional futures can be proposed. This chapter’s exploration and findings assist with forming alternative medical planning solutions for future hospital space.

7.1 Defining ET principles: All about scale

This section describes the fundamental differences between existing and future technologies. This information supports designers with visualising the potentiality of ETs. The main component of differentiation is the scale in which technology is produced presently. Two scales dominate ET production: (i) microtechnology; (ii) nanotechnology.

(i) Microtechnology

Microtechnology, or micro-electro mechanical systems (MEMS), is defined as:

> A class of devices typically made from silicon or employing it in the fabrication process; devices integrate electronics and mechanical devices onto a single substrate with typical feature sizes in the 1- to 50-μm range (Peterson, 2004:17).

Microtechnology creates matter at the micrometer scale which is slightly larger than ‘nano’ scale production. This is calculated as ‘one thousand nanometres or one thousandth of a millimetre’ (House of Commons Science and Technology Committee (HCSTC), 2004:7). One of microtechnology’s most significant achievements was the invention of the integrated circuit (IC). This has assisted with the fundamental progression of technology since the 1960s. MEMS have dramatically improved technology performance while reducing costs simultaneously through sophisticated mechanical systems produced on chip technology (Burtis, 1995:215). ‘Commercially exploited for many years, for example, in the production of ever smaller electronic devices and more powerful small computers’, MEMS remain a developing technology with anticipated potentialities (HCSTC, 2004:7). Significantly, MEMS offer a wide range of possibilities as most ICs and micro-machinery required to work at this scale and the nano scale are produced at the microtechnology level. Current MEMS applications include micro-mechanical devices composed in products, such as, pacemakers, blood pressure monitors and drug delivery systems (Prime Faraday Partnership, 2002:6).

(ii) Nanotechnology

The conceptual principles of nanotechnology originate from Feynman's *There's Plenty of Room at the Bottom*. However, ambiguities in defining nanotechnology circulated throughout the scientific industry until recently (see Appendix G.2-3). A universal standard for defining nanotechnology was defined by the International Standardization Organization (ISO) Technical Specifications:

> The application of scientific knowledge to control and utilize matter in the nanoscale, where properties and phenomena related to size or structure can emerge (ISO/TS 80004-1:2010).

At present, the ISO specifies nanotechnology as:

> Intentionally produced materials that have one or more dimensions on a scale between about 1 and 100 nm (Hischier&Walser, 2012:271) (see Figure 7.1).

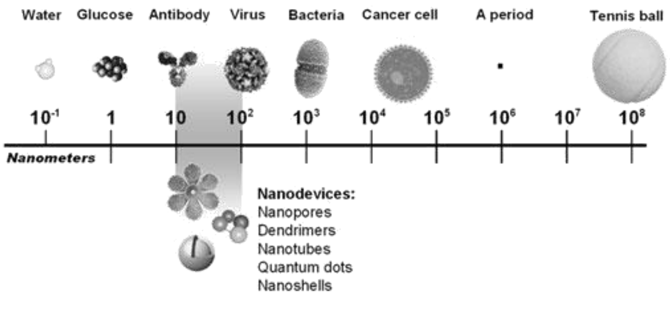


Figure 7.1 Scale of nanotechnology from a medical perspective.

Generally, nanotechnology is the application of engineering and science where 'at least one dimension is on the nanometer scale (one-billionth of a meter)' (Sahoo et. al., 2007:20). As argued by Dr. Jerome Glen:

> Nanotechnology is more of an approach to engineering than a science (Glenn, 2006:129).

Nanotechnology is already a multi-billion pound worldwide market and is incorporated into thousands of products across numerous industries, such as, healthcare, electronics, and materials (Morose, 2010:285).

7.1.1 Analysis: Micro v nano

There are two distinct approaches to fabrication which sets microtechnology and nanotechnology apart. Both fabrications need not be detailed here but their compositions, and section findings, are tabled in Appendices G.4-5. From this data, the study determines that the difference in technology type and scale are irrelevant to this thesis' focus on hospital space as both technologies share common outcomes and goals:

> Both approaches can work within both biological and nonbiological systems, bridging important divides between the biological and nonbiological worlds (Horton & Khan, 2006:43).

Suffice to say, the approach taken within the thesis identifies nanotechnology as a slowly progressing technology while microtechnology continues to strive towards reaching its technological potential. Nevertheless, over the coming decades, progress from both types of technology will offer great medical changes under the technological umbrella of medical ETs.

7.1.2 Degrees of certainty: Driving factors for technology success

The same companies involved in developing micro-nano technologies conduct current R&D of medical technologies. This R&D relationship is allowing the healthcare sector to be one of the first industries to benefit from anticipated ETs (Sahoo et. al., 2007:21). Four drivers for technology success are considered in this study to bring perspective to predicted medical ETs: (i) finance; (ii) time; (iii) consumers; (iv) hazards and ethics. Detailed in Appendix G.6, findings conclude that finance will not impede upon the long-term achievements of ET progression. This perspective is supported by an ongoing trend of technology growth that defies economic recessions. Furthermore, medical technologies have enormous potential as computer expert Andy Kessler argues, ‘silicon means smaller, cheaper, faster, better’ technologies (Kessler, 2006:183). Additionally, any medical ETs that can reduce the cost of staff salaries is worth developing to decrease the NHS’s largest expense. Alternatively, timescales associated within nanotechnology production need to be reduced to allow for ETs to become affordable. However, with medical ETs requiring health and ethical approvals, time and costs will be added which will drive the success or failure of all medical ETs. On this basis, biotechnology, robotics and cybernetics were chosen for this study’s exploration as their technology is predicted to be fairly matured by 2025. Therefore, a relationship diagram for future medical ETs discussed in the study is established in Figure 7.2.

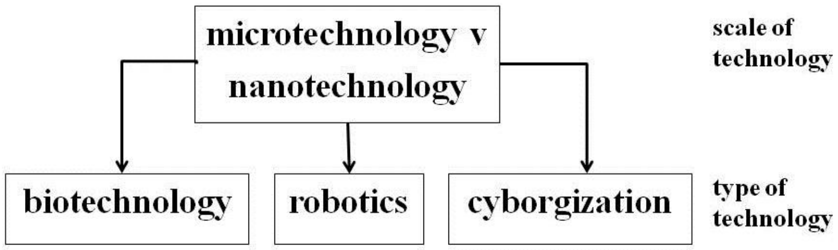


Figure 7.2 Hierarchy diagram of medical ET relationships as per Figure 3.1.

7.1.3 ETs in healthcare

The role of ETs in healthcare is twofold: to improve the delivery of care; increase staff productivity. While the medical field is forecast to benefit greatly from future technology developments, ETs have a presence in hospitals already through the use of microtechnologies. For example, existing products include activity monitors, chemotherapy and pacemakers as well as insulin pumps, hearing aids and needless injectors. Existing technologies will continue to develop and produce faster and cheaper equipment most likely to be smaller in size based on this study’s identified trend for medical technology size development. Other existing ET equipment includes robotic machines, such as, Stereotaxis which scans 3D human body maps. Of note is this machine's ability to be operated by only one not-so-skilled person. This new ET replaces the need for three very expensive doctors. This equipment typifies how medical ETs can be advantageous, particularly to hospitals where staff and fiscal shortages persist. At present, Stereotaxis equipment is installed at UCLH and the Royal Brompton Hospital, London, highlighting medical ET's descent into NHS hospitals.

While not covered within this study, IT has become a vital component of hospital technologies by transforming the delivery of NHS healthcare since the 1980s. Digital x-rays, instant medical records and wireless technologies, which allow for quicker diagnoses, represent the type of interactive tools available to clinicians currently. Future healthcare delivery will be improved as a result of IT progression. The spatial implications of IT are a discussion outside the scope of this study.

The emergence of nanomedicine:

> Offers ever more exciting promises of new diagnosis and cures. It has been defined as the monitoring, repair, construction and control of human biological systems at the molecular level (Chan: 2006:218).

Through an ability to repair, renew and replace human tissues and organs, 'recent advances suggest that nanotechnology will have a profound impact on disease prevention, diagnosis, and treatment' (Sahoo et. al, 2006:22). So positive, physicist Robert Freitas Jr. claims 'in the first half of the 21st century, nanomedicine should eliminate virtually all common diseases of the 20th century' (Freitas, 2005: 244):

> In an array of new medical devices....it is hoped that development of these nanodevices can help physicians to locate the problem areas in the body more precisely (Chan, 2006:220).

This is the fundamental difference between existing and future technologies which encourages 'most drug companies in the world to engage in nanotechnology' (Chan, 2006:218). Basically, the new concept for medical practice is located at the atomic level. In brief, technologies need to transform to be able to assist clinicians with working at an atomic level. Generally, nanomedicine is in its early stages of production in comparison with other industries. Limited examples exist within the medical field as only the testing of products has been accomplished. This leaves human clinical trials and full medical approvals to be achieved. To date, findings have been positive:

> The results of the relevant studies confirmed the potential of nanostructures in regenerating different tissues (such as bone, cartilage, bladder, nerves and vessels) (Engel et. al., 2008:42).

Realistically, Freitas suggests that 'the greatest power of nanomedicine will emerge, perhaps in the 2020s' (Freitas, 2005: 244). This study believes that progress will be witnessed initially by the medical ETs discussed in the following sections.

7.2 Biotechnology: Definition and background

As per the 'UN Convention on Biological Diversity',

> Biotechnology means any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use (United Nations, 1992:3).

Biotechnology is not a novel invention. The centuries old manufacturing of beer, cheese and milk are all products of 'biotechnology'. Recently, many industries, such as, agriculture and the chemical industry, have flourished from applying biotechnologies (Colwell, 2002:216-7). Consisting of sub fields, red biotechnology is associated with medical productivity[2]. This incorporates the manufacturing of antibiotics and genomic manipulation:

> Using GMOs to produce vaccines and biopharmaceuticals, tissue cloning to produce organ replacements or to repair damaged tissues (Black et. al., 2010:16).

Historical medical biotechnology events include Jenner's smallpox discovery, 19th century research conducted by Pasteur and Lister and the revolutionary discovery of

---

[2] See Glossary.

Watson and Crick’s DNA double helix structure (1953). Of note was the early-20th century pharmaceutical revolution which has transformed lives since the 1940s. Patient survival from surgery and vaccine discoveries represents biotechnology’s ‘modernization of an old technology’ (Colwell, 2002:216-7). Recently, microchip technology has developed the field of genetic engineering whereby more vaccines and antibiotics have been developed, such as, interferon to progress the speed of non-invasive treatments. The benefits of modern biotechnology allow for existing medicines to be produced easier and cheaper, such as, clotting factors for haemophiliacs or fertility drugs for expectant couples (Walsh, 2003:4). Overall, biotechnology has revolutionised medical practice and the function of hospitals. During its development, biotechnology events have affected NHS hospital space in different manners. Related examples, previously addressed in Chapter 5, include the spatial impact of introducing syringe equipment and the boom in post-1940s pharmaceutical production.

7.2.1 Biotechnology future trends

The potential for medical biotechnologies is considered certain as productivity works at the molecular, rather than, the atomic level. Three anticipated biotechnology trends emerge as significant as their impact will revolutionise existing healthcare practices. In doing so, changes to medical technologies and practices will challenge the existence of many UAT hospital spaces.

(i) Pharmaceuticals: Future developments in biotechnology are anticipated to produce new ‘custom made drugs’ and ‘drug delivery systems’. Briefly, the outcome will create a radical new agenda of personalised medicine. Changes will be made possible by the growth in physiological and anatomical molecular knowledge. Both ETs will be driven by an emerging new medical field:

> Pharmacogenomics is the study of the genetic basis for the differences between individuals in responses to drugs in order to tailor drug prescriptions to individual genotype (Destenaves & Thomas, 2000:440).

Presently, the pharmaceutical industry maintains a ‘one-drug-fits-all’ mentality (Sadee, 2011:2). For example, ‘interferon B is only efficient in one out of three cases of multiple sclerosis’ (Destenaves & Thomas, 2000:440). One medical detriment from mass-produced drugs is patient adverse reactions. This clinical outcome directly affects A&E space due to the high demand of chronic acute patient admissions. For example,

> In the United States alone, it is estimated that adverse effects are the fourth to sixth major cause of death and that hospitalizations due to adverse drug reactions cost from $US 30 billion to $US 150 billion a year (Destenaves & Thomas, 2000:440).

This financial statistic equates to over 100,000 patient deaths per year (Schmitz et. al., 2001:43). Therefore, the necessity for custom-made-drugs to be realised is driven by numerous factors that aim towards minimising patient mortalities. Contextually, the Royal Society predicts (2005) the realisation of pharmacogenomics is ‘at least 15-20 years away’ (Boon & Moors, 2008:1916). This anticipation suggests that hospital spatial implications are set to commence by the 2020s. While descriptions of personalised drug equipment are not clear from literature, as a medical planner, this study’s prediction for Pharmacy is a spatial increase in size. This prediction is based on a future requirement for extra machines to produce a wider range of pharmaceutical products. Each new machine will require its own large sterile room and add substantial amounts of area to aseptic suites. Additionally, extra storage for manufactured products will need to be considered, particularly for pharmacy robots where their size is driven directly by a hospital’s drug supply volumes. Alternatively, the delivery of ‘custom made drugs’ will be conducted through a number of new drug delivery systems ‘such as nanospheres, nanocapsules, microemulsions, macromolecular complexes and ceramic nanoparticles’ (Stylios, 2005:S7). Methods of administrating target delivered drugs are predicted to remain as per current medical practice. This encompasses topical, inhalation, oral and transmucosal medical processes that can be administered in existing hospital spaces.

(ii) Point-of-care testing (POCT) and Lab-on-a-chip (LOC): The second emerging biotechnology trend relates to patient monitoring and testing. The first of these is point-of-care testing (POCT) which the Royal College of Pathologists define:

> An analytical test undertaken by a member of the healthcare team or by a non-medical individual in a setting distinct from a normal hospital laboratory (Lee, 2004:2).

POCT is conducted upon body fluids, exhaled breath and cardiac markers. They are distinguished from other pathology equipment by their recent capability to produce test results remotely within an hour (Kumar & Arrowsmith, 2006:341). In 1999, POCT was a concept anticipated to arrive shortly (Borriello, 1999:298). By 2010, biotechnology advancements have produced almost real-time molecular devices that are operated in all hospital departments. Current POCT diagnostic equipment 'encompasses a wide variety of testing media ranging from simple reagent strips to sophisticated handheld and bench-top analysers' (see Appendix G.7). A desired goal for future POCT is for equipment to be linked electronically:

> (POCT) will have telecommunication capabilities...with direct links to medical informatics systems and physicians providing real-time tele-healthcare (Leary, 2010:453).

As per recent trends in micro-nano technologies, it is envisioned that future POCT equipment will continue to decrease in equipment size.

The spatial impact of introducing POCT equipment has been twofold across hospitals. The first spatial impact is area reduction for placing testing machines. This trend responds directly to smaller portable and handheld medical equipment. This outcome leads to a second spatial impact which is driven by the decentralisation of pathology testing. This trend has created ‘a paradigm shift from the central laboratory’ to beyond the Pathology department (Fermann & Suyama, 2002:401). Since 1999, the spatial boundaries of Pathology have witnessed the redistribution of laboratory spaces throughout the hospital. For example, new POCT rooms are being incorporated into CCU and OT departments in the latest PFI Royal Liverpool University Hospital (2013). Anticipations for spatial change are for Pathology spaces to evolve as new POCT products become available in response to micro-nano technologies. For example, the next generation of POCT equipment will become networked and require extra office type spaces for pathologists to download information for clinical diagnoses.

Figure 7.3 Left: Portable (handheld) blood analyzer i-STAT System which provides real-time, lab-quality results in minutes (Rios et. al., 2012:7). Right: Full size, floor standing blood analyser (Nottingham Spirk, 2012).

A driving factor of POCT is ‘LOC’ technology. This is formed upon biotechnology developments that are created from new genetic knowledge. LOC technology became available commercially in 1999. This revolutionary event has miniaturised medical technology considerably since 2000 (Andersson & van bed Berg, 2004:44):

> Over 1000 patents have been issued in the USA alone for 10-year period 2000–2009. The application fields of analytical miniaturized devices have been clearly expanded (Rios et. al., 2012:6).

To exemplify the recent trend in medical technology size reduction, Figure 7.3 pictures a portable (handheld) POCT machine with its comparable full size floor standing testing equipment. Both emergency tests and large batch samples would have been run on the same large blood analyser prior the invention of LOC technology. Currently, LOC technology offers clinical options which are supported by alternative spatial requirements.

The aim of future LOC development is micro-miniaturisation. The goal is to create portable technologies through the use of nano-biosensors. Applications of this technology are becoming marketable already. For example, a baby-grow suit called *Babyglow* changes fabric colour in response to a baby’s high temperature (2012). During the course of the study, continuous patient monitoring devices have reached a sophisticated level of diagnostics where fabrics embedded with nanoparticles are able to monitor patient vital signs (Leary, 2010:453; Stylios, 2005:S12). For example, *VivoMetrics Lifeshirt System*[3] has adapted LOC technology to allow doctors to monitor patients’ real-time health remotely (Combs, 2006:1309). This LOC’s potentiality is wide ranging, particularly for paramedic products. A novel μPAD fluid technology is emerging that will assist with developing LOCs by providing bio-analyses with ‘little or no external supporting equipment or power’ (Rios et. al., 2012:7). This ET will hugely reduce the size and weight of future medical equipment but, fundamentally, forms the basis of the predictions of Kurzweil and Kaku for future ubiquitous technologies.

The latest concept for advanced LOC technology is to implant a chip under the skin. This is the basic principle for ‘laboratory-in-a-cell’ (LIC) technology:

> To perform complex biochemical operations, and to employ advanced micro- and nanotechnological tools to access and analyse this laboratory and to interface it with the outside world (Andersson & van bed Berg, 2004:44).

Theoretically, LICs will produce instant diagnostic results while dispensing targeted drugs simultaneously. The outcome will control patients with ongoing chronic conditions to no longer suffer from chronic-acute attacks (Freitas Jr., 2005:329). The

---

[3] Ventura, California – is a multichannel cardiopulmonary digital recorder that can be worn 24 hours a day and monitored remotely. Received FDA approval in 2002.

department in which LICs will be implanted initially will remain debateable for some time. The thesis suggests this medical process will take place in minor op rooms (OPD) or OT rooms during neurological implantations. One major spatial implication to result from this preventative care medical technology will be the reduction of assessment areas in A&E. LICs will reduce the large patient numbers from being admitted to A&E, thus, relieving the need for observation and monitoring areas for chronic-acute cases.

(iii) Molecular engineering: Molecular engineering is the third biotechnology trend anticipated to revolutionise current medical practice. Three main areas of growth include genetic testing, gene therapy and cloning. Most of these biotechnology disciplines relate to long-term and preventative care which will impact spatially on OPDs, Pathology and Oncology departments. Aside the future treatment and curing of genetic or acquired diseases, cloning will be practiced upon UAT patients admitted for emergency care. Cloning is classified into two categories of reproductive and therapeutic cloning[4]. Reproductive cloning will not be a reality before 2050 due to ethical challenges. In contrast, therapeutic cloning promises to create self-healing and repair materials based on new self-assembling nanotechnologies. Hybrid bio-devices will assist with developing tissue engineering and organ development. Using microtechnology for 3D body scanning, precise details for new hip and knee replacements will replicate body parts, such as, bones, artificial veins and neuron cells (Combs, 2006:1309-10; Cui, 2005:16). Significantly is the predicted timescales for the realisation of cloning techniques. ‘Commercially viable solutions of such products are thought to be 5-10 years away’ (Stylios, 2005:S8). However, with *The Lancet* recording its first successful windpipe transplant, its otolaryngology surgeon Martin Birchall argues:

---

[4] Reproductive cloning is completed within humans. Therapeutic cloning is conducted within laboratory conditions.

> This will transform the way we think about surgery. In 20 years, the commonest operations will be regenerative procedures to replace organs and tissues (Laurance, 2008:2104)

Similarly, orthopaedic consultant Philip Chapman-Sheath at the Spire Southampton Hospital (2011) had re-grown a patient's knee successfully by stitching on laboratory grown cartilage cells to the patient's dysfunctional joint (Adams, 2011). Based on these successful treatments and professional forecasts, the study anticipates cloning to be infiltrating into general medical practice and hospitals by 2015. The spatial implications for incorporating cloning techniques will affect Pathology, OT, Imaging and A&E trauma sections as described next.

7.2.2 Spatial analysis of future biotechnology implementation

Predicted biotechnology trends portray a radical departure from current medical practice many of which will relate to preventative and long-term care. This section outlines the spatial implications projected to occur in a variety of acute-care departments.

One purpose of pharmacogenomics is to eradicate the side-effects of mass produced pharmaceuticals. 'Custom made drugs' will evolve future clinical demands by reducing adverse drug reactions. This clinical change will relieve the pressure on overcrowded NHS A&E spaces by reducing A&E patient admissions. This anticipated decline in service demands will be supported by newly introduced LIC technology. As a result, future demands for patient observation and treatment spaces in A&E will subside. This predicted spatial trend contradicts the current medical planning models; acute assessment ward type areas are being added to A&E departments to cater for 24-36 hour chronic-acute patient monitoring. This new development creates medical planning problems by adding extra services, space and flows to existing very congested and expensive clinical hospital floors. Additionally, the use of single patient bedrooms at the

A&E level increases inter-floor structural complexities as column design layouts for higher floor levels clash with the new cellular bedroom design below. This new problematic medical planning model is a response to what is envisioned to be a short-lived medical demand. Therefore, for the sake of reducing in-patient beds to achieve present healthcare policies, the thesis identifies the current A&E medical planning model as incompatible with future medical ETs and practice. This scenario causes concern as it echoes the historic events of post-1980s Nucleus hospitals where inflexible hospitals were incapable of responding spatially to the aggressive pace of evolving medical technologies and models of care.

The complexity of surgical operations being practised in A&E trauma bays is anticipated to expand clinically as molecular engineering progresses. For example, organ transplants in A&E will become a desired model of care as the minimisation of patient movement in critical conditions is of utmost priority. Therefore, larger enclosed sterile high-spec trauma rooms will become a future necessity in A&E to cater for increased trauma patient transplants. This outcome raises two critical medical planning issues. The first issue is the need to transform trauma spaces from open bay areas into high-tech OT rooms. This will challenge the concept of many NHS hospitals' centralised OT department but suggests that the future functionality and spatial boundaries of A&Es are set to evolve. This study argues that this medical planning revolution has commenced already with A&E's newly introduced adjacent Satellite Imaging department. The second critical issue refers to the structural design of A&E's future medical planning model. The structural design of A&Es will need large column free spaces to operate as trauma surgical suites effectively. Therefore, the thesis stresses structural foresight future A&E expansion strategies must be considered in current A&E and whole hospital medical planning models.

The incorporation of anticipated biotechnologies will drive Pathology and Pharmacy areas to increase in size from their current HBN standards in the following ways. Findings reveal that new pharmaceutical manufacturing will require additional aseptic clean rooms. This change in production will demand a much larger Pharmacy department based on the spatial guidance from HBNs. As much as 400sqm of extra space would be required for only a minimal amount of new biotechnology procedures. For Pathology, new cloning techniques will require space for larger floor standing equipment and extra walk-in fridges and freezers for storing cloned tissues and organs. Furthermore, additional laboratory spaces and offices, necessary for visiting medical team members, will add area to each laboratory while introducing new medical planning relationships between clinical and laboratory areas.

Since this study commenced, LOC technology has been realised in the form of POCT equipment. Spatial implications exist already in dedicated POCT NHS hospital rooms (10sqm each). Based on short-term predictions for micro-nano and LOC technology progression, POCT equipment is anticipated to decrease in size while becoming more plentiful throughout all acute departments. Versatile LOC technology was shown to have a diverse range of medical possibilities. Wearable continuous monitors and LIC technology both have the potential to challenge the existence of certain current medical equipment. For example, ECG equipment could be made obsolete once ‘medical jackets’ are introduced into mainstream hospital practice. The spatial outcome will de-clutter hospital spaces, such as, triage, A&E observation and treatment rooms. In response, patient areas will be observed as less clinical but raises the option for rooms to become slightly smaller in size. However, these developments only represent the beginning of events that will witness technological micro-miniaturisation. Findings reveal that medical technology sizes are anticipated to decrease with the aim of becoming environmentally ubiquitous and surgically implantable. This is not an obscure concept as cardiac implantable electronic devices have existed for many years as pacemakers. Emerging upgraded models will connect to doctors' mobile phones when clinical abnormalities arise (Brinker, 2012:1626).

Generally, the biotechnology revolution will deeply impact on hospital space and question existing medical planning models. For example, ubiquitous POCT technology will replace POCT rooms with 'continuous monitoring' observation centres created for medical teams to congregate and discuss patient data. Alternatively, LIC technology will require access to OTs and minor procedure rooms as chip implants and maintenance become regular practice based on bi-annual computer software upgrades. Subsequently, it is foreseen that a whole new department will emerge for LIC treatment explicitly based on the spatial trend that new medical technologies result in new departments. Links to UAT departments will be needed for access to emergency cases. To summarise, future biotechnologies are anticipated to revolutionise current medical practices. This prediction signifies the genesis of spatial transformation which concurs with section 4.2.5's analysis of medical design influences.

7.3 Robotics: Definitions and background

Labour forces became an expensive industrial commodity over a century ago. Innovative scientists and engineers developed robotic machines to replace expensive staff. The purpose of robotics still stands today; to replace jobs that people would prefer not to do or jobs which robots can far outstrip human capabilities. The International Organisation for Standardisation (ISO8373) officially defines a robot:

> An automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications.

Catering mainly for large factory assembly lines, robotic knowledge was transferred only recently to the medical field in 1985 (Valero et. al., 2011:542). Medical robotic innovation has created two types of hospital robots: (i) non-clinical robots that support hospital activities; (ii) clinical robots that assist medical team members and patients during surgery and therapy.

(i) Non-clinical robots

Pharmacy is one department benefiting from current non-clinical robotic progression. Medication errors were statistically high (approx. 37%) and financially burdening all healthcare systems (Felder, 2003:S6). To resolve this issue, pharmacy dispensing robots were created to increase efficiency and productivity. Available 24/7, the purpose of dispensing robots is to free up expensive pharmacists to concentrate on important clinical and patient work. Outcomes from employing dispensing robots have been proven to reduce medical errors greatly (Jerrard, 2006). In turn, dispensing robots are improving patient safety and reducing unnecessary fatalities. While widely used in America, robotic dispensing machines are a recent introduction into NHS hospitals, for example, *DORIS* at the Pembury Acute Hospital, Kent (2011). Additionally, robots have been created to produce intravenous (IV) solutions. *Robotic IV Automation* (*RIVA*) is one robotic example which prepares 60 doses of IV solutions per hour. Both pharmacy machines are spacious in volume and have driven the recent size of NHS Pharmacies. Pharmacy robots, as identified, are sized upon production volumes (see section 5.2.4). On this basis, and including identified biotechnology trends, the study predicts future robot sizes will increase in size and therefore require additional hospital space. The same outcome is anticipated for Pathology equipment as the demand for robotic testing and sampling increases as future biotechnology productivity expands.

Industrial robots have been adapted to transport hospital medication, laboratory specimens, supplies and medical records, such as, the *HelpMate* robot. These robots are unrestricted to departmental confinements as they operate along corridors (out-of-hours) or through pneumatic tube systems in service ducts (24/7). These processes decongest corridors while reducing cross contamination and infection growth. To assist with FM’s flow of hospital goods, AGVs are the predominantly used floor mounted type of robot. However, opinions amongst experts are divided upon the use of AGVs in hospitals. In the case of the new Forth Valley Hospital, Stirlingshire (2007), healthcare architects and trade unions commented that ‘the system was risky and could lead to job losses, health and safety issues’ while Keppie Design’s director, David Starck hailed the robots as ‘the next logical step’. Alternatively, chair of Architects for Health, Ann Noble, argued that the robot system was ‘very impressive’ while healthcare architect Mungo Smith (Mapp Architects) described the robots as ‘boys toys’ for an inappropriate hospital solution (Ancell & Crump, 2007:3). Opinions aside, the incorporation of non-clinical robots is growing momentum as all of the above robots are functioning successfully in present NHS hospitals. Spatially, AGVs and similar robots have impacted on hospital space as extra area has been added randomly for hospital storage, maintenance and transport routes across hospitals.

(ii) Clinical robots

The study defines clinical robots into three categories of rehabilitation, surgical and human assisted robots.

Rehabilitation robots incorporate prosthesis and assisted therapy robots. These creations support patients with natural defects or patients recovering from physical impairment or stroke. One of the first surgical procedures in hospitals was limb amputation which responded to medical adversities, such as, bacterial meningitis and pneumococcal septic shock. Contextually, diabetes is responsible for 40% of British amputation cases in NHS hospitals (Marshall & Stansby, 2008:21). The replacement of missing body parts has existed for many centuries but the development of robotic and enhancing prosthetics has developed enormously since 2008. Sensor technology has allowed for upper limb motion to progress while optimised physiological gait technology (2011) has improved lower limb prosthesis. Examples of prosthesis include the *iLimb* robotic fingers and hands by Touch Bionics, Otto Bock's C-leg and Genium's leg models (Clement et. al. 2011:337; Johnson, 2011:22). All of these prostheses are anticipated to be bypassed by a new generation of neurological high-tech models. The merging of prosthesis and neurology is an emerging medical practice discussed in section 7.4.

Prof. Brian Davies at Imperial College, London defines surgical robots:

> A powered computer controlled manipulator with artificial sensing that can be reprogrammed to move and position tools to carry out a range of surgical tasks (Davies, 2000:129).

Davies divides surgical robots into two categories:

1. Passive robots move to an appropriate position but are powered off during surgery
2. Active robots have manipulators with tools that directly interact with patients when performing surgery. Classifications are broken down further by surgeons' interaction with robots: supervisory-controlled (Cyberknife); shared-control; telesurgical systems (Ponnusamy et. al., 2011:570).

The first reported use of surgical robots was in 1985. As a recent invention, surgical robots have improved 'clinical parameters, such as blood loss, length of hospital stays, and complications' (Ponnusamy et. al., 2011:575). As both Ponnusamy et. al. and Valero et. al. trace the history of surgical robotics, historical events will not be described here. Suffice to say, the revolutionary invention of *ROBODOC* (1990s) was a defining moment in medicine. This surgical robot innovated surgical practice to create minimal invasive surgery (MIS) (Rattner, 1999:12). Progressing to perform cardiac surgery by 1998, MIS now performs abdominal and orthopaedic surgery with high anticipations for future neurological and gynaecological surgery (Dorozynski, 1998:1696). The practice of MIS and keyhole surgery is forecast to grow as medical robots continue to enhance surgeons' dexterity (Rattner, 1999:14). Clinical outcomes from robotic and MIS developments involve quicker patient recoveries as well as fewer post-operative infections and relapses. Examples of existing passive robots include an x-ray guided catheter robotic arm which undertook its first heart operation at Glenfield Hospital, Leicester in 2010 (Radnedge, 2010:23).

The fore leaders in active surgical robots include *AESOP, HERMES* and *da Vinci* as well as *SOCRATES* and *ZEUS* robotic machines[5]. The most well known, the *da Vinci* robot, was functioning within six NHS hospitals in 2008 (see Appendix G.8-9). By 2012, the *da Vinci* robot was operational in numerous NHS hospitals including the Royal Marsden, Torbay and Southmead Hospitals (NHS Choices, 2012). Significantly, the use of robots in surgery has created a paradigm change to surgical practice. Surgeons no longer need to perform directly on patients or be situated within the same room. For example, at Glenfield Hospital, the catheter robotic arm was operated by surgeon Dr. Ng in an adjacent control room. The desired minimisation of staff exposure to radiation was made possible through remote-controlled robotic use. Similarly, the *da Vinci* robot consists of two pieces of equipment; a robotic arm and console unit. The surgeon works from the remote-controlled robot but remains located in the same room as radiography is not involved. The outcome of surgical robotic use is driving a new medical planning departure. The relocation of Cath. Labs. into OT departments is

---

[5] Only two companies worldwide develop robots. They have developed *AESOP* and *HERMES* which both use voice activation, *SOCRATES* which was used for the first transatlantic telesurgery and *ZEUS* which is used for endoscopies.

merging the two modalities of surgery and imaging. Robotic technology is therefore contributing to the ‘blurring’ between surgical and diagnostic practices. In its ability to change models of care, surgical robots are affecting hospital space both directly and indirectly. This is represented by the increase in MIS which, in requiring less POSs, has increased the demand for surgical day-ward bed spaces. This medical planning change is raising similar issues associated with the design of Acute Assessments in A&E as the preference to locate day-wards adjacent to OTs is adding medical planning complexities while pressurising existing over loaded hospital D&T floors.

Obese and elderly populations are predicted to escalate substantially. Future nursing problems are anticipated to emerge from coping with increased demands and a shortage of staff. These concerns underpin the driving necessity for human assisted robots which have been created to assist staff with patient care tasks, specifically lifting and monitoring patients. From this background, substantial investment has been provided to develop human assisted robots. Presently, clinically tested robots are set to emerge in hospitals in 2015, such as, the ‘Robot for Interactive Body Assistance’ (RIBA-II) (Schwartz, 2011) (see Appendix G.10).

7.3.1 Clinical robotic future trends

This section explores anticipated trends for two types of clinical robots.

(i) Surgical robotics: Three robotic trends highlight the future scope for surgical robots.

NHS uptake of surgical robots has been slower than American hospitals as machines cost approximately £1.2 million each with a £100,000 yearly maintenance (Davies, 2006:S54). A financial investment of this scale for one piece of equipment must be justified by individual NHS hospitals. While Trusts await clinical evidence, technology maximisation has been reviewed financially to argue the case for robotic use in NHS hospitals. Hence, the recent surge in the number of NHS robots is witness to the clinical and economical advantages of surgical robots. Therefore, the use of robots within daily surgical practice is anticipated to continue delivering cutting-edge surgical interventions (ECRI, 2009:5):

> The da Vinci® Robotic Surgical System also has limitations, the main one is still size; it limits the space in the operating room; moreover, it has a lot of delicate connections that are inside the operating room that may cause accidents or can be damaged if not used adequately (Valero et. al., 2011:542).

Suggested improvements ‘encompass advances in sensors with new imaging modalities, haptic feedback, and manipulators with novel instruments’ (Ponnusamy et. al., 2011:575). Expectations visualise future surgical robots to be more intelligent, smaller with improved surgical appliances. These improvements do not compare to the future anticipations for artificial intelligence (AI) controlled robotics:

> In 2010, Duke University bioengineers demonstrated that a robot - without human assistance – can locate a manmade or phantom lesion in simulated human organs,...researchers believe that as technology is developed, autonomous robots could someday perform many more simple surgical tasks (Valero et. al., 2011:544).

These predictions indicate a trend for surgical robots’ to become fixed items within future OT rooms. Spatially, upgraded surgical robots are anticipated to be smaller in size which will require no additional space in OT rooms. Nevertheless, extra OT rooms may be needed for increased patient volumes availing of new robotic surgical procedures.

The second trend is based upon a shift in surgical practice introduced through telesurgery over a decade ago. Telesurgery interacts between real and virtual environments using virtual reality, surgical robots and medicine. For example, the first transatlantic operation witnessed Dr. Marescaux perform telerobotic surgery using a *ZEUS* surgical robot in 2001 (Valero et. al., 2011:541). In the NHS, telesurgery is an enormously under-utilised existing medical technology system which, as NHS costs escalate rapidly, offers an alternative solution that maximises the employment of expensive technologies and expert medical staff. Therefore, this study strongly emphasises the use of telesurgery as essential to the efficiency of future NHS surgical practice. Benefits from expanding telesurgery also have spatial positives, as its equipment does not alter the size of OT rooms. For example, to operate telesurgey, additional internet-connected cameras are installed. These are normally ceiling or pendant mounted to avoid the intrusion of equipment in staff working zones. Additionally, telesurgery offers an opportunity to reduce the size of OT rooms. Regional resourcing can organise for one hospital to have all surgical robotic equipment, while smaller satellite OT rooms in other hospitals need only install robotic arms.

A third surgical robotic trend originates from Feynman's 'swallowing the surgeon' concept.

> A friend of mine (Albert R. Hibbs) suggests a very interesting possibility for relatively small machines...it would be interesting in surgery if you could swallow the surgeon (Feynman, 1960:22).

Feynman's novel proposal has been the basis of post-1960s scientific R&D where the hope for micro-robot technology is to allow surgeons to diagnose patients internally. To date, the 'swallowing' of diagnostic equipment exists primitively in the form of endoscopes and catheters. Recent inventions have produced small digestible devices the size of an oral pill (Bradbury, 2000:2074). This technology was bypassed quickly by the superior aspirations for controllable data micro-robots that download and transmit internal information to clinicians externally. By 2010, Italian scientists have developed 'an autonomous but navigable capsule that patients can swallow' (Bradbury, 2000:2074). Similarly, test results by Palali et. al. conclude that 'the first step towards development of smart micro-robots for human body application' is underway (Palagi et. al. 2011:265). At Imperial College, London, a primitive form of this type of surgical robot is being developed. The *iSnake* weaves around the body equipped with lights, high frequency cutters and sealers (Darzi, 2007:7). These examples contextualise the status of 'swallowing the surgeon' robotics but support the trend of an approaching new radical change to the existing medical agenda. For example, 'swallowing the surgeon' devices will assist with the decline of open surgical procedures through anticipated nano-robots:

> Introduced into the body through the vascular system or at the ends of catheters into various vessels and other cavities in the human body (Freitas, 2005:245).

The anticipation for nano-robots is to perform both diagnostic and surgical procedures:

> Surgery in the future will no longer be about blood and guts, rather it will be about bits and bytes (Satava, 1998:691-2).

The application of nanorobots is not believed to occur prior to 2050 but robotic expert Prof. Brad Nelson reports that this may be brought forward as clinical trials were injecting small robots into humans in 2005 (Nelson & Rajamani, 2005). Aside unpredictable timescales for the realisation of micro-nano robotics, the spatial impact of incorporating 'swallow the surgeon' robots will be driven by what the thesis understands is two factors. The first factor relates to the intravenously injected administration of future micro-nano robots (Freitas, 2005:245). Equipment for this procedure is essentially a syringe or catheter which maintains existing hospital space sizes. As a result, this equipment is accounted for spatially within existing HBN room areas. However, surgeons will need access to 3D image scanners to identify the internal locations of injected micro-nano robots. This second factor, on the other hand, will require additional hospital space and demand more hybrid OT rooms to operate clinical efficiencies. Hybrid rooms presently range between 75-100sqm and are much larger than standard NHS OT rooms at 55sqm (Rostenberg & Barach: 2012:58; HBN 26). Section 7.3.2 examines the spatial and medical planning changes that result from a revolution in emerging surgical robotics.

(ii) Human assisted robots: Three examples highlight the wide-ranging possibilities predicted for human assisted robots.

The first example is cognitive humanoid robots which are based on biological systems knowledge (Zielinska, 2009:541-58). With the most difficult mechanical abilities overcome recently, such as, walking, programmed emotions and ability to sense touch, the creation of an interface that humans find acceptable is being developed. Typical examples include *Asimo, HRP2* and *KOBIAN* humanoid robots (Quan et. al., 2011:1527-34; Allen, 2010:133-5). *iCub* is the most academically acclaimed 'at the forefront of research in cognitive systems and robotics'[6] (Mettaa et. al., 2010:1133). The future of humanoid robots is argued to be in the form of 'a realistically simulated flexible spine humanoid robot'[7] (Or, 2010:459-60). Progression in this direction will greatly improve robotic capabilities which are envisioned to have a physical presence in hospitals by 2020. Types of roles these robots will accomplish include administration tasks, for example, greeting patients in a supporting capacity and patient portering.

A second group of robots assists clinical staff with the observation of and lifting of heavy patients. Medical staff are not always available to answer questions from patients and family members. The outcome drives feelings of 'not knowing' and 'neglect' which directly increase patient stress levels. Human assisted robots help reduce patient worries

---

[6] A six year joint European Commission robotic venture (2004-10).

[7] Of the Institute of Human Performance Research Laboratories, University of Hong Kong.

by combining existing technologies to deliver and transmit basic information. The *u-BOT5* model typifies the potential of future hospital robots which consist of web cams, microphones and wifi technologies (Mosher, 2008) (see Appendix G.12). This robot reminds patients to take medication and gives estimated times for test results while virtual conversations with clinicians increase patient confidence and use specialist staff effectively. A prototype of this kind is being tested at the Chelsea and Westminster Hospital, London (Imperial College, 2006). The *Remote Presence* (*RP6*) robot requires no spatial changes as it utilises existing staff spaces and circulation routes (see Appendix G.13). However, investigations are necessary to understand the complete spatial impact should high numbers of *RP6* models be operated throughout hospitals. Robots that assist with lifting patients are typified by the previously mentioned RIBA-II type model. Imaging, A&E and OT departments will benefit from these robots by minimising patient injuries during critical care patient bed transfers. Of note, area to manoeuvre robots around patient trolleys needs to be considered spatially.

The third group of human assisted robots focuses on improving staff welfare and work efficiencies. These robots aim to: reduce staff illnesses, such as, back strain and pulled muscles; relieve nursing staff from general duties to concentrate on nursing patients; reduce medical errors by replacing tired staff. Recent robots are being developed to conduct repetitive clinical tasks to replace expensive highly-skilled medial staff. For example, the *R2* replaces radiologists from evaluating hundreds of mammography scans and the need for two expensive radiologists (Kessler, 2006:105). This floor-standing computer-aided detection-scanning machine reduces the need for hospital space by half.

Generally, all human assisted robots will need space for storage, maintenance and re-charging. Storage space, for technologies no longer in use, can be utilised for storing clinical robots throughout hospitals. In contrast, the Bio. Eng. department will need to increase in area substantially to cater for expanding demands of maintaining all types of clinical robots.

7.3.2 Spatial analysis for future clinical robotics in hospitals

Each future clinical robot generates its own spatial dimensions but, generally, the underlying trend for future robots is smaller and intelligent equipment. The outcome will require no extra space as surgical robots, telesurgery and human assisted robots all anticipate hospital space to be unaffected by their technology's operation. Additionally, the long-term prediction for 'swallowing the surgeon' robots anticipates medical equipment size to decrease which correlates with earlier identified thesis trends for technology development. Two significant 1:200 and 1:500 medical planning outcomes emerge aside the potential inefficiencies of oversized existing hospital rooms.

The first significant 1:200 medical planning change is the increased size of the Bio. Eng. department. Predicted growth in clinical robots will drive the need for extra maintenance services and space for increased robot numbers. The scope for Bio. Eng. is to extend beyond its building envelope at a ground floor level as this department is located typically adjacent to hospital exteriors or basement levels.

The second major medical planning impact involves changes to the OT and Imaging departments. This is driven by the clinical necessity to scan patients during future surgical practices. Spatial options include: new scanning rooms to be added to OT rooms; OTs to be relocated to Imaging. Either way, extra area will be added to create new hybrid OT rooms in one of two high-tech departments. From a medical planners' experience, the preferred solution is to extend existing OT departments to reduce bedded patients travelling to and around public levels. However, this 1:500 option opens up medical planning issues and raises concerns for many PFI hospitals where space for hybrid OT rooms is not catered for generally. The problem for both 1:500 option is sourced from hybrid OT rooms being 50% (approx.) larger than existing OT room sizes. A typical problem is the inability of OT departments to expand adjacently due to their normal building location existing on upper hospital floors. In this scenario, a replan of the OT department to include hybrid OT rooms will result in fewer OT rooms and a reduction in surgical productivity. One could argue that medical ETs will decrease current surgical demands but this trend will be offset against the major increase in new treatments resulting from medical ETs. Therefore, to maintain the number of existing OT rooms, expansion must be undertaken on adjacent floors. However, this option may not be available if UAS is unavailable or floor-to-floor ceiling heights are incompatible. Another typical problem to emerge from larger OT rooms is existing column design layouts. For example, PFI NHS OT departments have been planned to an absolute minimum, forcing alternative solutions to be challenging or impossible to replan. While some hospitals have accounted for one shelled-out OT room (55sqm), findings reveal that single extra spaces are inadequate as a future spatial expansion strategy. Instead, flexible space needs to be distributed evenly throughout the OT department to allow for future imaging control rooms to be built. This study draws attention to these anticipated trends, as they typify the characteristics associated with driving NHS hospitals to become obsolete.

The above medical planning problems only slightly indicate the extent to which one medical ET will impact on future UAT treatments. Hence, the study determines future clinical robots will impact upon future hospital space profoundly.

7.4 Cyborgization: Definitions and background

Scientifically, a cyborg is simply categorised:

> An organism with both biological and electronic parts (Krause et. al., 2011:369).

The scope of a cyborg ranges from 'the all-too-human pole at one end to artificial intelligence (AI) devices at the other' (Williams, 1997:1047). Two types of 'medical' cyborg exist: restorative and enhanced (Williams, 1997:1042). Cyborgization is the study and process of restoring or enhancing cyborgs.

(i) Restorative cyborgs: Restorative cyborgization repairs and restores lost functionality of organs, limbs or systems to improve a human's standard of well-being (Gray, 1995). Cyborgization is formed, generally, upon one of two technology forms; bionics and AI technology. The application of bionic devices is joined to the human body surgically through synthetic feedback mechanisms. Each performs a specific biological function, for example, neural prosthesis for cochlea implants or neural stimulation for stroke patients. A wide range of bionic applications exist which include automated insulin pumps, cardiac pacemakers and titanium hip replacements (Gray, 1995:2-3). As a result, many medical cyborgs exist already with numbers set to grow enormously. Presently, AI technology is not as advanced as bionic technology as biological systems and brain activity are not easily replicated. AI technology is forming a new type of cyborg composed of surgically embedded chip technology, such as, Prof. Kevin Warwick, University of Reading (see Appendix G.14).

(ii) Enhanced cyborgs: Enhanced cyborgs follow the principle:

> Of optimal performance: maximising output (the information or modification obtained) and minimising input (the energy expended in the process) (Lyotard, 1984).

The technology of enhanced cyborgization replicates restorative cyborgization. Fundamental purpose is the distinguishing factor differentiating the two types of cyborgs. Enhanced cyborgs are driven by technology's ability to augment physical or mental capabilities. Restoration plays no part in the enhancement of the humans' mental status or physique. For this reason, enhanced cyborgization is unapproved ethically and is not considered further within this study's exploration (Warwick & Ruiz, 2008:2623).

7.4.1 Future cyborgization trends

Transplantation for limb replacement was an avant-garde medical practice at the end of the 20th century. However, practicalities were found to be problematic when attempting to find appropriate matching limbs. In realising these disadvantages, medical attention was redirected towards medical ET's new capabilities. A new generation of prostheses resulted benefiting the agility of users immensely. However, with emerging micro-nano technologies and new neurological medical knowledge, promising techniques are predicted to benefit future cyborgs, such as, bio-engineering, medical cybernetics and synthetic biology.

> Basic research aiming at understanding the fundamental mechanisms of how the brain generates movements has become more and more relevant for clinical application....To improve the versatility of motor prostheses, an important enhancement would be to include sensory feedback from the actuated (artificial or natural) limbs (Scherberge, 2009:631).

From this background, future prostheses will become more subconscious through functional electrical stimulation. This has been proven to work for artificial hands and bladder control for motor neuron patients already (Warwick & Ruiz, 2008:2620). Improvements in battery life and biomaterials are creating the next generation of lighter and more efficient prostheses but current R&D is developing new materials:

> Suitable for direct fixation to the bone allowing considerable reductions in the weight of the constructs and conferring additional strength to the limb (Clement et. al., 2011:338).

Briefly, sensory technology will produce myo-electric prosthesis that will merge technology and human biology through surgical attachment of prostheses to human bone. In general:

> The advancements in this field of medicine are exponential and it is likely that within 10 years there will be commercially available limbs that provide both sensation and accurate motor control from day 1 (Clement et. al., 2011:339).

With the first bionic eye implanted in 2008 (Moorefield's Hospital), the thesis acknowledges the anticipations for this medical ET are set to expand and succeed (Humayun et. al., 2012:779-88).

AI is implanted into humans using radio frequency identification (RFID) chip technology. Its function is to mimic neurological functionality of patients with physical disabilities, such as, severe spinal injuries. Current progression in this field is sourced from two recent medical ET developments. The first source is human implant RFIDs which have been developed by Applied Digital Solutions. Their *VeriChip* is capable of tracking medical records by scanning chips within bodies. In the future, patients, and particularly on-going chronic patients, are anticipated to have RFIDs embedded to provide paramedics and clinicians with instant access to medical information (Levine et. al., 2007:1709-11). The second source is derived from neuronal activity experiments which 'bring thought-controlled computers, mechanical devices, and prosthetic limbs a step closer to reality' (Birchard, 1999:52). While Birchard predicted that thought-controlled artificial limbs were a long way from realisation, the first thought controlled robotic hand was fitted in 2009 at the Campus Bio-Medico in Rome, Italy (Rossini et. al., 2010:777-83). The most famous cyborg of this type, Prof. Kevin Warwick, implanted an RFID chip into his arm to 'present a glimpse into what might be possible in the future' (Warwick & Ruiz, 2008:2623). Warwick's AI research is dedicated to correcting the neural signal abnormalities in Parkinson's disease with outcomes intended to benefit many other neurology conditions. For example, by linking RFID implants to the human nervous system, future AI can correct decaying nervous systems by transmitting neural signals directly to control a multitude of therapeutic and medical devices (Warwick & Ruiz, 2008:2619). AI cyborgization remains in its infancy due to the difficulty in attaching current thick cables to the nervous system. In due course, developments in micro-nano technology will create more compatible products for easier connectivity to cyborgs' brain and nervous systems.

7.4.2 Spatial analysis for future cyborgization in hospitals

Introducing the practice of cyborgization into hospitals will create many novel medical treatments. Potential spatial outcomes are categorised into three major medical planning trends.

The first spatial trend responds directly to the introduction of bionic technologies. This outcome will maintain, if not increase, patient numbers attending OPD clinics, such as, Rehab and Neurology. While this aspect of healthcare delivery relates to on-going patient care, attention is drawn to the future of OPD space which, generally, is designated as 'soft-space' for future high-tech departments. This expansion strategy is based upon recent healthcare policies that intend to disperse OPD services to local NHS facilities. However, this finding for bionics reveals that the demand for OPD space will remain as per current demands. This identified trend contradicts current medical planning strategies and undermines the future spatial growth of high-tech departments.

The second spatial trend is for OTs to grow in departmental size. This spatial change will be driven by increased surgical demands that result from new bionic and AI implantations. For example, the instalment of prosthesis is undertaken presently as a medical treatment in Minor Ops rooms (25-46sqm). Alternatively, bionic prosthesis will be conducted as an interventional or interoperational procedure in high-spec hybrid OT rooms (70sqm). This change in medical practice will require a new bionic prostheses service that will multiply the quantity of complex surgical operations and demand for OT space. Similarly, AI cyborgization requires neurosurgical operations for both implantation and extraction (Warwick & Ruiz, 2008:2623). The surgical process of implanting RFID chips was recorded by Warwick as taking two hours to complete[8]. This insight supports a spatial trend; extra OT rooms will be needed to cater for emerging and additional surgical services. A new medical planning model is emerging, to support the future of neuro-surgical developments, at the Brigham and Women's Hospital and Harvard Medical School, USA (2011). The Advanced Multimodality Image Guided Operating (Amigo) suite combines technologies from Neurology, Imaging and OTs (see Appendix G.15). This model is designed as three interlinked rooms and focuses on brain tumour treatments presently. However, to substantiate the financial cost of a 530sqm high-tech OT unit, the Amigo model must become functionally adaptable to allow for other operations. From the perspective of NHS hospitals, a shift to this design model would either impact heavily on a hospital's medical planning or be disregarded completely as an option due to spatial inabilities to adapt (see section 7.5).

The third spatial trend witnesses the emergence of a new medical planning dynamic for Bio. Eng.. As per Weeks' second 'duffel coat' theory, the contextual status of Bio. Eng. is one of internal departmental expansion only. However, a shift in Bio. Eng. expertise will become essential during clinical consultations and surgery. This involves a previously non-existent interface between biomedical engineering staff, patients and

---

[8] Undertaken by surgeons from the Oxford Radcliffe and National Spinal Injuries Centre Hospitals.

surgeons. This alteration will establish biomedical engineering staff as key members upon future neuro-surgical teams. This development creates new spatial relationships between Neurology, Rehabilitation and OT departments. As a result, Bio. Eng. will evolve on two levels: (i) expand spatially for increased service demands; (ii) relocate adjacent to Neurology or OT departments to accommodate for new spatial adjacencies that support a prostheses practice that is becoming osseo-integrated. Overall, the spatial impact of this new medical planning dynamic will pressurise existing D&T hospital floors further.

7.5 Discussion of medical ET implications on future urban acute hospital space

This section revisits the relationship diagram established in section 7.2 and updates the original version with informed chapter findings (see Figure 7.4). The study believes the new diagram represents a more accurate account of the inter-relationships between medical ETs where an unidentified technology emerges centrally from the cross-diversity of disciplines. This novel technology is the longer-term future for medical ETs and indicates the direction of progression for future medical technologies.

Key trends revealed in this chapter are listed in Table 7.1. This list informs the discussion of spatial trends and medical planning implications addressed in the following sections. Of note, no indications for future x-ray technology emerged from the three medical ETs explored. Hence, future imaging equipment size remains inconclusive within this study. However, the study anticipates the Imaging department to continue to evolve as per the medical planning implications mentioned next.

List of identified trends: Medical ET implications upon UAT treatments			
	ET trend	**Medical trend**	**Spatial trend**
Biotechnology	Custom made drugs. LIC technology	Change in practice. Management of chronic acute illnesses. Reduction in chronic acute attacks.	A&E: Assessment areas to reduce
	Future POCT & LOC equipment	Reduction in testing equipment size. More portable.	Small equipment dispersed throughout hospitals
	Micro-miniaturisation of biotechnology	Reduction in monitoring equipment in size and quantity	Spatial decrease as technologies become embedded in patients' garments and environment.
	Upgraded Pharmacy equipment	Smaller mobile technologies. Continued paradigm shift away from centralised hospital laboratory services.	Small spaces throughout hospital. Pharmacy to increase in size.
	Molecular engineering	Growth in pathological services	Pathology to grow in size. Relocation of Pathology to be nearer A&E and OT.
	Therapeutic cloning	Increased surgical activity. Replication of bone, tissue, etc.	Additional space to OT and Pathology. Relocation of Pathology to be nearer A&E and OT.
Robotics	Human assisted robots	Introduction into general hospital practice	No space added unless in large quantities
	Nanotechnology surgery	Substantial developments in complex neurology and brain surgical practice	New model for hybrid OT rooms
	Telesurgery	Increased presence of telesurgery in OT	No space added
	Surgical robots	1. Development of MIS and keyhole surgery. 2. New 'swallowing the surgeon' surgical practice.	1. Reduction in OT room size. 2. New model for hybrid OT rooms.
Cyborgization	Surgically implanted bionic and AI technology	Surgical, imaging and pathology demands increased	New model for hybrid OT rooms
	Neurological and prosthesis technologies	Cyborgization introduced into hospital practice	Creation of new neurological Robotics-Cyborgization department.

Table 7.1 List of identified trends from chapter findings.

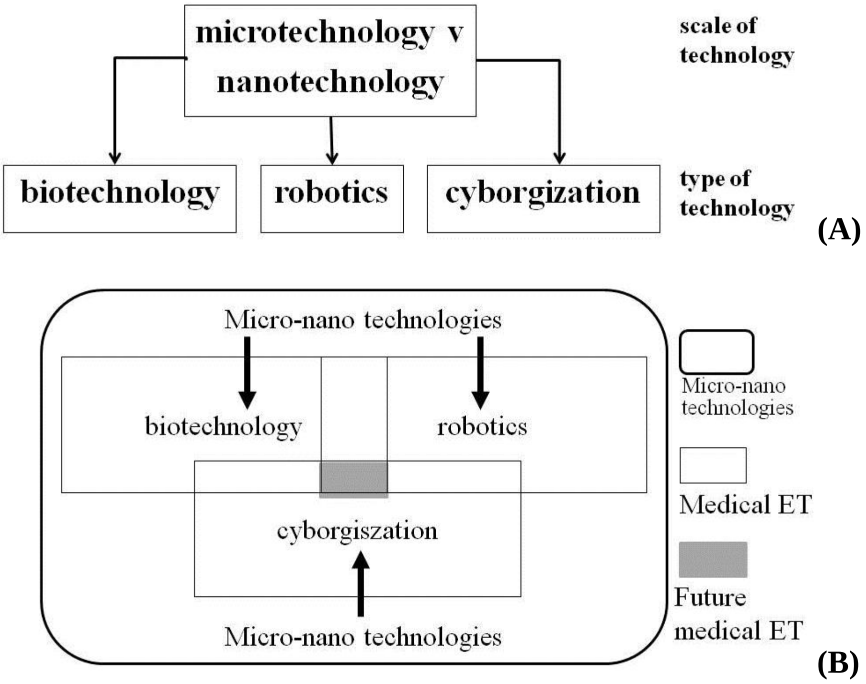


Figure 7.4 (A): Figure 7.2. **(B):** Updated diagram of Figure 7.2 highlighting the relationships of explored medical ETs.

7.5.1 Future A&E hospital space

The strategic medical planning location for A&E is not envisioned to change based on A&E’s pertinent need for direct external access (see Figure 7.5). Internally, its 1:200 spatial impact will be one of continual evolution. Changes over the next twenty years will occur effectively in two evolutionary stages.

The first stage is one of hospital spatial growth which results from three driving factors. The first influence is the need for extra observation area caused by deteriorating epidemiological problems. Traditional medical planning methods of soft-space utilisation can resolve A&E’s need for additional area. For example, adjacent open plan offices can be converted into clinical observation bays (if available). Events from the remaining two driving factors will occur simultaneously. These are new A&E imaging services and the up-grade of trauma facilities. Presently, Satellite Imaging is gaining an adjacency beside A&E departments. This study recommends that this spatial entity should become embedded as emergency imaging within A&E instead. This proposal will be driven by clinical aspirations to perform complex procedures in A&E where trauma facilities will need to be upgraded to replicate the design of OT suites. Both changes will require additional space and add complexities to designing A&E departments. For example, to upgrade from a trauma bay to a single OT suite requires an extra 99sqm[9] of space. However, UAT practices will be compromised if hospitals are incapable of expanding. This spatial trend will be challenging for many acute hospitals where a minimum of three trauma bays will need to be upgraded.

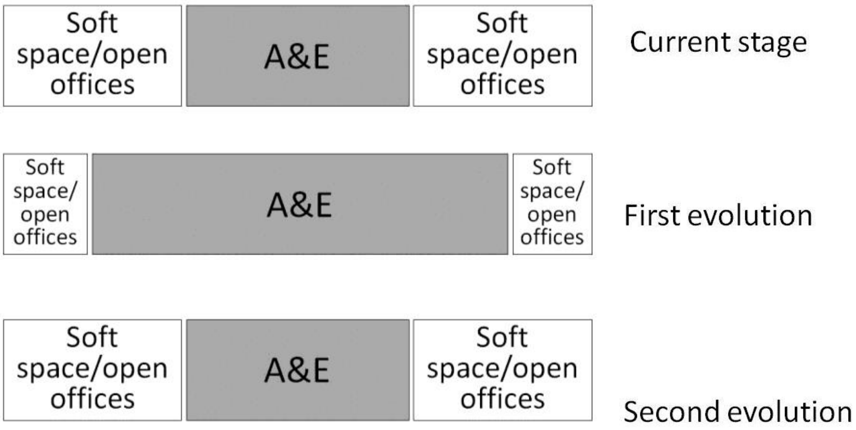


Figure 7.5 Diagram of spatial trends for A&E.

The second evolutionary stage will be one of spatial retraction driven by changes in clinical demands resulting from the use of custom-made-drugs and LIC technologies. The demand for A&E observation spaces will decrease leaving 400sqm (min.) of void A&E space[10]. Therefore, the study advises that A&E and adjacent departments must be designed as a joint unit to allow for future spatial flexibility.

The size of individual A&E clinical spaces is not expected to change, particularly for major observation cubicles and medical assessment unit (MAU) rooms. This is based on upgraded POCT and LOC technologies which are forecast to reduce the number and

---

[9] Based on a trauma bay of 29sqm (HBN 22) and a single OT suite of 128sqm (HBN 26).

[10] Based on a 50% reduction of a typical MAU department of 45 patient rooms at 750sqm excluding other A&E observation areas.

size of testing equipment. For example, Prof. Tim Coates (University of Leicester/Leicester Royal Infirmary) is conducting R&D into smart ‘sick bays’ which detect disease by sight, smell and feel (University of Leicester, 2011). Such applications highlight the growing relationship between biotechnologies and hospital space. In this case, patient monitoring medical technologies are intended to become ubiquitous which will reduce the need for equipment space. Similarly, additional space will not be required when human assisted robots are introduced into A&E. These robots will be designated to function within existing spaces previously occupied by medical staff. A final consideration for storage, and the re-charging of new medical ETs, needs to be accounted for spatially when designing for future A&Es.

7.5.2 Future laboratory hospital space

Hospital laboratory spaces will be affected mainly by biotechnology developments. Possible outcomes stem from one of two distinct and existing business models: in-sourced or out-sourced laboratory work. A decision to contract-out work responds to Weeks’s ‘duffel coat’ theory for laboratory expansion which is a strategy to maintain its spatial size (Architectural Record, 1970:102) (see section 2.1.2). This scenario will maintain departmental areas through a reduced scope of services, future smaller equipment and designated soft-space for future internal expansion. Alternatively, to in-source future work that responds to internal and regional demands will incur changes in three ways in laboratory departments.

The first change will be an immediate increase to laboratory departmental areas. Spatial expansion will be driven by an enormous expansion in future laboratory services. For example, the delivery of custom-made-drugs and molecular engineering will require a large amount of extra equipment. Each machine will require additional high-spec clean rooms of 37sqm each. Therefore, strategic plans for Pharmacy and Pathology must account for an additional 200-450sqm (minimum) each for the development of future laboratory departments that in-source laboratory work[11].

The second spatial change will result from the continuing shift towards decentralised laboratory services. A more visible presence of mobile laboratory equipment will appear throughout NHS acute hospitals. New types of medical technology will require scattered flexible space for future upgraded equipment which is anticipated to decrease in size and eventually becomes ubiquitous.

The third spatial change will affect the medical planning location of Pathology. This relocation will result from the change in dynamics between pathologists and future medical teams. Closer working relationships between surgeons, pathologists and radiographers will benefit from being located nearby. Thus, to reduce staff travel distances, Pathology needs to relocate adjacent to OTs. At present, this Pathology adjacency does not exist in many NHS hospitals. The thesis advocates the long-term evolution of Pathology must be kept in mind for future medical planning strategies.

7.5.3 Future surgical hospital space

The introduction of non-clinical robots established a robotic presence within hospitals. The spatial impact has created new pockets of space for re-charging and storing robots. More significantly, their precedence has been psychologically vital to introducing clinical robots into surgical practice, such as, the *Scuplture* robot for orthopaedics and the *da Vinci* robot for urological MIS. Diagnostics and treatment will become increasingly non-invasive as the next generation of surgical robots and endoluminal

---

[11] Based upon four new clean room suites, at 214sqm each, in two departments.

surgery emerges. By 2025, the scope of medical ETs will include patient treatments, such as, injected LIC, the reconstruction of body structures through biotechnology while cyborgization will be a well-established hospital medical practice.

The spatial impact of current MIS technology is the reorganisation of space within OT rooms while future surgical robots are anticipated to decrease in equipment size. This finding contradicts current medical planning practice which ‘super-sizes’ OT rooms on the basis of recent past technology trends which anticipate future medical equipment to be larger in size. However, a more overarching outcome will result from incorporating medical ETs into surgical practice. A Trusts’ clinical preference for radiography access will result in one of two spatial potentialities. The first scenario includes scanning equipment within OT rooms which would be resolved spatially by converting either a shelled-out or adjacent OT room. This option creates one large hybrid OT type room which is 27% greater than HBN guidance (55sqm). The second scenario locates scanning facilities in an adjacent room to OT rooms with sliding partition walls inbetween for medical equipment access. This solution, represented by the Amigo model, maximises scanning equipment usage by creating a dual approach to accessing high-tech imaging machines. However, this Amigo type OT room is almost tenfold the HBN area for an OT room. A shift to this model will impact heavily upon existing clinical productivity and NHS hospital space. Ironically, this option may be unfeasible for ‘state-of-the-art’ PFI NHS acute hospitals which will result in cutting-edge clinical functionality not being sustained in PFI NHS acute hospitals.

Based on the above scenarios, the expectation is for OTs to expand substantially. This study proposes that new departmental ‘boundaries’ must be formed to cater for OT spatial evolutions. At present, Imaging and OTs function as separate clinical entities where the transfer of bedded patients between departments is unacceptable. The rational solution is to eliminate these flows by creating two contained OT/Imaging departments. Each contains a mixed composition of spaces and supporting medical technologies. The first proposed department would consist of a hybrid OT/Imaging suite that conducts complex high-tech interventional operations. This new unit would have direct adjacencies with Pathology and Bio. Eng. facilities and incorporate an Amigo type medical planning model. The second proposed department will utilise existing OTs and add imaging activities adjacent to OT rooms. This scenario will be made possible by smaller technologies that perform non-invasive procedures in smaller surgical spaces. An opportunity for new rooms to be created can emerge from an efficient re-planning of OT departments. New spaces that result will be allocated as control rooms for new imaging modalities or as interdisciplinary team meeting rooms for discussing pathological and engineering data.

7.6 Chapter analysis

Chapter 7's aim was to understand how existing UAT treatments will be affected by anticipated medical ETs. While the realities of medical ETs are not yet fully understood, a broad spectrum of possible spatial ET trends was revealed through the examination of biotechnology, robotics and cyborgization anticipations.

> Projecting these changes forward makes it certain that healthcare provision in the future will look very different, requiring new models of hospital design and new relationships (Future Healthcare Network, 2004:6).

Significantly, predictions for medical ETs identify the continuation of an existing technology trend; medical equipment size decreases as its technology progresses. This critical finding supports the study's concern that many existing NHS hospital spaces are sized incorrectly. From chapter findings, spatial implications emerge as numerous and wide-ranging which the study believes will impact deeply on future medical planning models. A number of key spatial trends were identified as an outcome from delivering future UAT practices. These identified trends inform Chapter 8’s scenarios and alternative medical planning solutions for future urban acute hospital space.

Chapter 8: Formation of future scenarios

"The best way to predict the future is to design it"

Buckminster Fuller

8.0 Introduction

Chapter 8 is dedicated mainly to achieving the third thesis objective. This is to visualise the spatial consequences of incorporating medical ETs into hospitals. Drawing from Buckminster Fuller's principle that, *the best way to predict the future is to design it,* this chapter creates alternative visions for future UAT hospital space. The chapter opens with discussions upon the study's technological and spatial findings which inform the suggestions for future medical planning solutions that follow. Thereafter, spatial visions are delivered through three scenarios that typify UAT patient admissions to NHS acute hospitals in the year 2025. Each scenario examines the potential spatial impact of five high-tech departments: A&E; Imaging; OT; Pathology; Pharmacy. Additionally, Chapter 8 aims to achieve the fourth and final thesis objective. This is to assess the necessity of flexible design solutions particularly with respect to PFI NHS hospitals.

8.1 Discussion of findings regarding ETs

This section offers a technology vision for the future-proofing of hospital space. Six main ET trends inform this alternative vision for 2025. These include: (i) growth of 'smart' technologies; (ii) utilisation of App technology; (iii) micro-miniaturisation of biotechnology; (iv) robotics; (v) nanomedicine and 'swallowing the surgeon'; (vi) cyborgization.

(i) 'Smart' technologies: Physicist Michio Kaku argues the progression of computer technologies will become so affordable, invisible and intelligent that future technologies will become ubiquitous (Kaku, 1998:8,36). On this basis, and the existence of emerging marketable 'smart technologies', unlimited potential is anticipated for the creation of future 'intelligent' hospitals. This technology vision will be achieved through digital technologies sprinkled onto surfaces, such as, walls, furniture and clothes that create new technology interfaces that respond to touch, vision and speech. Eric Drexler, in his *Engines of Creation*, similarly argued the potential of ‘smart’ materials (Drexler, 1987). Video wallpaper, the ability to choose your paint colour on command and nano fluorescence that detects environmental contamination were visualisations waiting to be materialised once paper-thin technology was invented. In 2013, this technology was manufactured as *PaperTab* by Plastic Logic (Cambridge, UK). Benefits to architectural materials are anticipated to include paint with hearing capabilities and opaque changing glass that transforms glazed walls into privacy screens[1].

Haptic and force feedback technologies will develop new ways for delivering healthcare practices (Norman, 2007:193). Examples of products include; (i) integrated display furniture units that become visible worksurfaces when activated; (ii) motion activated virtual screens on walls that eliminate space hungry computers-on-wheels (COWs). Similarly, nurses will be able to retrieve patient data via virtual screens to show patients test results or iCloud intranet files for medical information.

Existing wireless technologies have limited capacity for medical equipment use. Future improved ubiquitous technology will allow, amongst other changes, future treatments to be unrestricted to specific rooms. In becoming less reliant on fixed power sources, enhanced wireless medical equipment will revolutionise technology’s relationship with hospital space by allowing treatments to be conducted in alternative hospital environments. New wired technologies will therefore offer medical planning options that will challenge existing hospital spatial design that currently responds to 20th century medical technologies and practice. Overall, future wireless ETs will reduce the number

---

[1] At present, ‘radio paint’ by BAE Systems Information has become a registered trademark (2010) while Trinity College, Dublin are developing a transparent film technology for manufacturing solar protected glazing (McDonagh, 2012:12).

of existing fixtures, fittings and equipment in hospitals. Their need for space will be decreased while indirectly reducing the alien feel of high-tech hospital environments.

(ii) App technologies: New technology interfaces will emerge in hospitals over the next 20 years but one significant recent ET is the invention of App technologies. This new technological platform utilises existing interfaces to inform and assist humans with daily activities. At present, App technology is under-utilised vastly within the NHS. The potential for this ET in NHS hospitals is extensive, ranging from economic and administrative efficiencies to patient stress reducing strategies. For example, an App that registers patients on arrival and directs them to their destination correctly creates a cost-effective, timesaving solution for staff trying to locate lost patients.

(iii) Micro-miniaturisation of biotechnology: Anticipated future environments will monitor patients' health through improved micro-miniature biotechnologies. For example, biotechnologies will be incorporated into WCs to provide instant toilet urinalysis (intelligent toilets by Toto, 2010). While no spatial change would result from upgrading sanitary equipment, the wider spatial impact is the elimination of Dirty Utility rooms (9sqm) adjacent to specimen WC rooms for testing samples. Alternatively, bio-sensors will be able to monitor infection levels or patient stress through colour changing intelligent clothing (Campbell, 2007:21). Similarly, the monitoring of patients through smell in 'sick bays' will be achieved through micro-miniature biotechnologies embedded in the environment that will reduce existing space for monitors (see section 7.5.1).

(iv) Robotics: Ray Kurzweil's *Law of Accelerating Returns* projects 21st century technology to change dramatically through the prominent development of robotics. This study identified four major robotic trends that will impact on medicine over the next 20 years; (i) increased presence of surgical robots for non-invasive and MIS procedures; (ii) nanorobotics and ‘swallowing-the-surgeon’ practices; (iii) increased telesurgery activity; (iv) introduction of human assisted robots. Each type of robot and their broad spatial implications were identified in section 7.3 but two issues of change are recognised by the thesis as significant. The first is an outcome from the continual merging of surgical, endoscopic and imaging modalities. A new super high-tech surgical suite will emerge to dominate and change medical planning models. Secondly, the growth in ‘virtual’ clinicians will evolve the relationships between medical technologies and hospital space. Robotic progression, and the holographic projection of absent clinicians, will allow hospital spaces to evolve in a less clinical manner.

(v) Nanomedicine and ‘swallowing the surgeon’: Fifty years on, Feynman’s vision for small surgical machines and ‘swallowing-the-surgeon’ have not been realised quite yet but ‘nanomedicine’ is beginning to emerge in medical practices with huge potential forecast (Feynman, 1960:29). Briefly, nanomedicine offers higher patient survival rates through faster diagnoses of illnesses. This is based upon a principle that, as patient physical symptoms arise, conventional medicine reacts to tissue-level problems only. Permanent and irreversible damage may result which, in contrast, nanomedicine promises to diagnose and treat problems at the molecular level prior to irreparable damage (Leary, 2010:453). As Freitas argues, profound changes are anticipated to appear by 2025 which include new medical practices of biopharmaceuticals, nanotherapeutics and surgical nanorobotics (Freitas Jr., 2005:328-9). Essentially, Freitas’s insight into future nanomedicine differs tremendously from existing medical practices.

(vi) Cyborgization: The emergence of cyborgization will be realised through novel bionics and AI technology. The impact from this technological progression is identified as forming a new integrated neurological Robotics-Cyborgization (RC) department. This new clinical arrangement and spatial entity within hospitals will alter the dynamics of hospital practice which, in turn, will require current medical planning models to change. Links with surgical and imaging facilities will dictate the location for a new RC department. However, preferred adjacencies with OT and Imaging will pressurise the future medical planning of hospitals.

Multiple trends inform this study’s medical ET vision. This scenario differs from the present so radically that a new medical agenda is suggested. In this event, hospital space will need to respond to a very different and in some cases ‘nano’ scaled type of technology. The next sections discuss and propose how hospital space can respond to future medical ETs.

8.2 Discussion of findings for current urban acute hospital space

This section discusses thesis findings with regards to current urban acute hospital space. Medical planning and spatial findings inform the assessment of flexible hospital design solutions in section 8.5. Additionally, broad trends identified in this section underpin the medical planning principles required to instigate a shift *towards a new hospital architecture*.

Current medical practices are presently very different from 50 years ago. Furthermore, bed numbers have been reduced considerably while current services have become patient-focused and heavily dependent on technology. Therefore, in questioning why hospital typologies remain similar to those of the mid-20th century, this study acknowledges that derivatives of the same hospital design model have been employed since the 1950s. This finding explains why hospitals lag behind in responding to the latest technological revolution which contradicts technology’s outcome from the ‘third wave of change’ as one of major evolution. Changes to hospitals are beginning to emerge but, from the perspective of a medical planner, 20th century medical planning principles of flexible space, economies of scale and adaptable hospital design strategies remain crucial to the success of future hospital design solutions. Furthermore, the four factors identified as central to the failure of late-20th century NHS hospitals must be kept in mind when searching for a new NHS hospital design model. These are availability of finance, the employment of cheap architectural materials, reduced HBN guided spaces and flexible standardisation, and are all fundamental parameters in need of consideration when designing 21st century hospitals For example, an ongoing awareness of economic situations remains central to designing sustainable hospitals as tighter budgets and increased healthcare demands inflict the use of spatial undersizing and cheaper materials. These latter two factors contributed to the failure of Nucleus NHS hospitals as both design influences conflicted with the simultaneous introduction of new medical technologies and their then continued growth in equipment size. Consequently, these events undermined spatial functionality. The juxtaposition of reduced built areas along with the spatial growth of new medical equipment reducing inflexible Nucleus NHS hospitals to a costly short lifespan. Hence, from an assessment of past and current hospital space, this study determines the following principle; short-term, quick-fix capital expenditure is not a sustainable solution for expensive publicly funded NHS hospital buildings.

A core element of the 20th century medical planning model reflects characteristics similar to those associated with Toffler's 'second wave of change' where spatial boundaries were identified, multiplied and sharpened.

> A new image of space arose that corresponded exactly to the new image of time. As punctuality and scheduling set more limits and deadlines in time, more and more boundaries cropped up to set limits in space (Toffler, 1980:124).

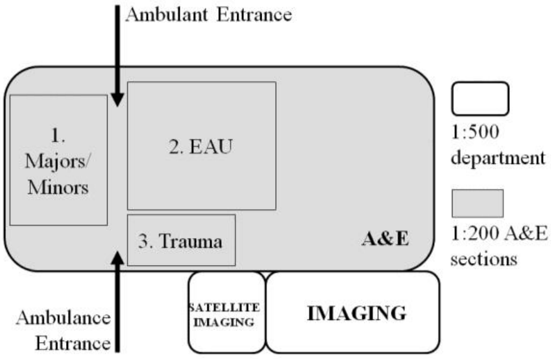
This division of space is represented extensively by the cellular design of 20th century hospitals where the multiplication of derived clinical spaces and office layouts prevailed. This culture of pigeonholing space leans towards human preferences rather than the needs of clinical functionality but embodies typical characteristics of the early-1900s technology era and principles of post-WWII spatial briefing. However, this restrictive tenet underpins the inappropriateness of recent and current hospital space which struggled to respond to ongoing post-1950s medical technology change. Therefore, this study proposes that a theoretical change to the fundamentals of spatial division creation are key to revolutionising current hospital space from its outdated 20th century medical planning paradigm.

This understanding of current hospital space forms the basis from which to project an alternative visualisation. Broad spatial trends inform this study's vision through three medical planning categories of 1:200, 1:500 and 1:1000 scales of design. Data regarding medical ETs are detailed in Appendix H.1 from which their spatial implications upon UAT departments are listed in Appendix H.2-3.

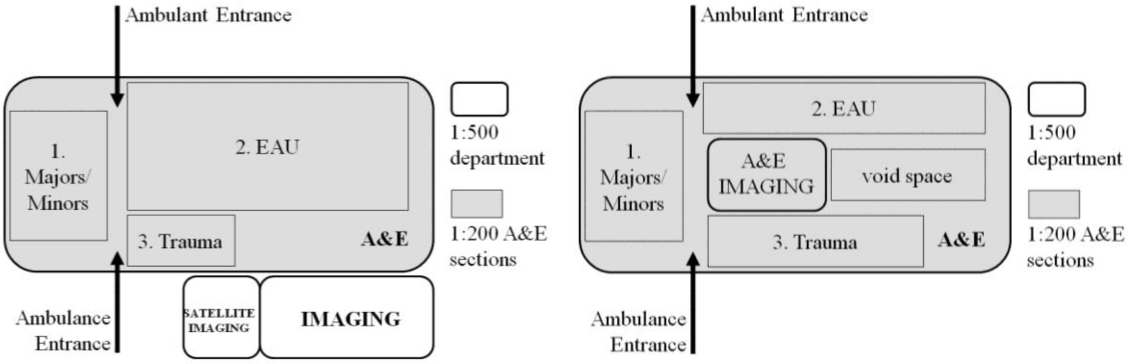
8.2.1 Discussion of 1:200 spatial implications

This section discusses 1:200 spatial implications which affect each of the five UAT departments in a different manner.

(i) A&E: By 2000, 25% of the British population used A&E departments on a yearly basis (Edwards & Harrison, 1999:1361). By 2025, this statistic for A&E admissions is anticipated to remain constant due to medical ET’s impact on changing the patient type. On this basis, the existing division of A&E departments is expected to continue as three clinical sections: (i) major & minor cabin areas for short-stay patients with cuts, bruises and breaks; (ii) Emergency Assessment Unit (EAU) for observing chronic and other patients for 8-36 hours in patient rooms; (iii) Trauma which consists of open resuscitation (resus) bay areas for emergency traumatic patients. Nevertheless, long-term spatial compositions will evolve as a result of two major spatial trends (see Figure 8.1).



Existing A&E department: Three clinical sections



Near future A&E department: Three clinical sections **Future A&E department: Three clinical sections**

Figure 8.1 A&E sections: Relationship diagram for existing, near and long-term futures.

The first spatial trend will affect EAUs as improved biotechnologies reduce the number of attending chronically ill patients. Hence, the spatial need for patient rooms will diminish as a result of decreased service demands. This large amount of future obsolete space will be further increased as A&E cabins reduce in size in response to smaller and ubiquitous LOC technologies. Some of this future void space can address the need for new and additional small spaces (1-4sqm each) for dispersed POCT laboratory equipment.

The second major trend is the upgrade of Trauma from existing resus bays to OT rooms. As identified, the delivery of all levels of surgery will be expected in future Trauma Suites. This model of care requires imaging facilities to deliver a high-tech trauma service but, by 2025, transporting trauma patients around hospitals will be medically unacceptable. Therefore, imaging rooms or adjacent Satellite Imaging departments, such as, examples at West Cumberland (2013), will become contiguous with future Trauma OT rooms. This outcome will be made possible only through the division of existing Main Imaging departments. This new controversial model of care will be necessary as more imaging activities shift to the OT department. As staff efficiencies become strained, inappropriate medical planning solutions would emerge should singular Main Imaging departments continue to be operated. On this basis, this study proposes that the Main Imaging department relocates next to OTs while A&E departments acquire their own imaging facilities. This spatial change will double the current size of HBN guided areas for trauma bays which excludes the additional areas for imaging equipment and support rooms.

Both spatial trends will alter A&E departments as internal space and medical planning flows are reorganised but a main concern is expressed for the intermediate growth of EAUs (400sqm minimum). For example, should this spatial event coincide with the area development of new Trauma Suites, the outcome will produce large spatial shortages that will impose major clinical problems upon A&E services.

(ii) Laboratories: On-site laboratory production is the policy chosen for many large urban acute NHS hospitals. This approach may differ in the future for numerous spatial and operational reasons. Presently, Pharmacy consists of Dispensary and Aseptic Suite areas. This study envisions these categories to remain but the size of each section is anticipated to grow. Alternatively, Pathology only contains one operational section but is composed of multiple sub-disciplines. The 1:200 area of Pathology is predicted to grow as additional new sections rather than expanding existing sub-disciplines (see Figure 8.2).

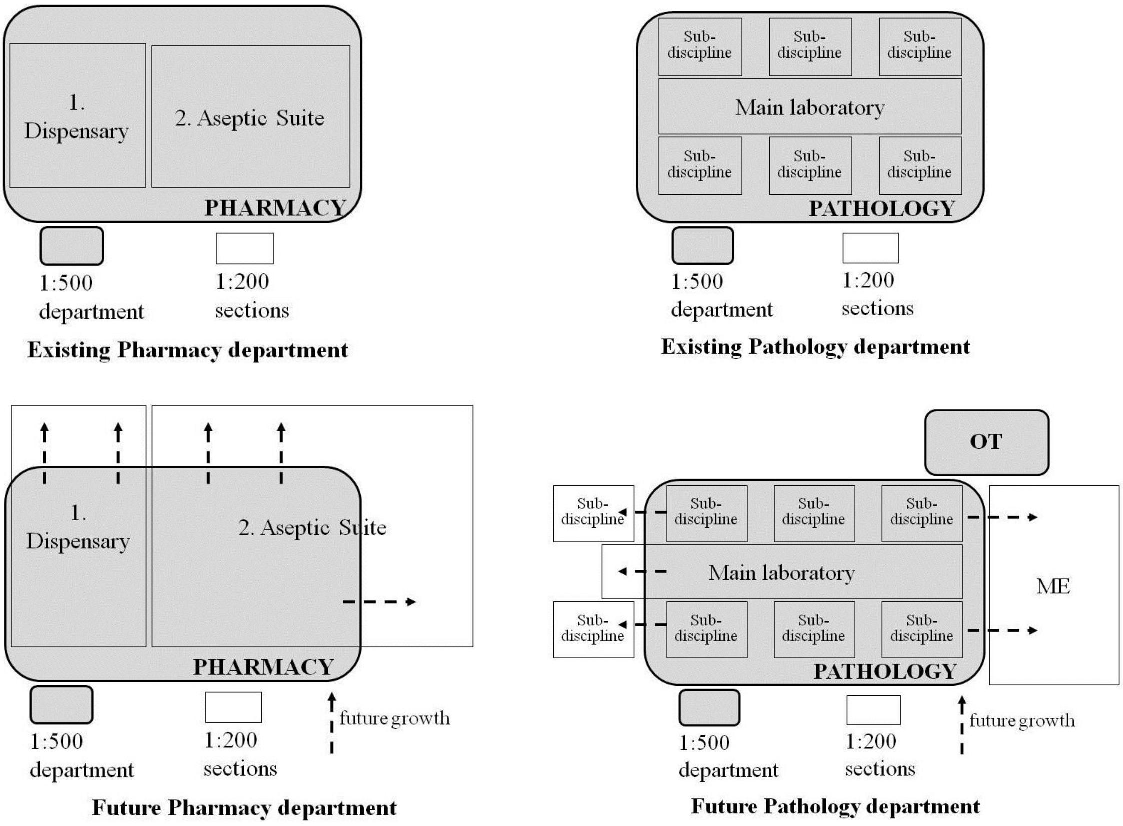


Figure 8.2 Laboratories: Relationship diagram for existing and long-term futures.

The development of Pharmacy space will be driven directly by newly imposed service demands resulting from the introduction of customised drugs and novel drug deliveries. New equipment for pharmaceutical production will be introduced which require extra aseptic rooms. These rooms plus their supporting rooms will increase Pharmacy size by 200-400sqm (minimum). Whether future pharmaceutical manufacturing remains on-site depends on a Trust’s preference or, more practically, upon the availability of expandable laboratory hospital space.

The potential of biotechnologies was acknowledged within a recent NHS design project.

> Advances in medical technology, particularly in biotechnology will drive service delivery changes, and lead to more treatments for more diseases (NHS, 2013:1).

Spatially, the future impact of medical ETs upon Pathology will be twofold. The first trend responds to a continued decrease in testing equipment size. As nanotechnology develops a wider range of smaller testing machines, pathology equipment will be decentralised further throughout hospitals. This continued trend will reduce the need for some existing Pathology spaces. By 2025, some tests will become ubiquitous and therefore require no space at all. In this respect, it could be argued that the 1:200 area of Pathology is set to decrease in size. However, the thesis believes this trend will be off-set against a second over-riding trend resulting from molecular engineering (ME) and cyborgization practices. A new ME section will be dedicated to support new laboratory equipment and functionality. Spaces will be similar to those within Aseptic Suites while walk-in freezer rooms will accommodate for grown tissue, organs and bone samples. Overall, the increase to the 1:200 area of Pathology will amount to hundreds of sqm of previously non-existent hospital space.

Only non-clinical robots will impact upon hospital laboratory spaces, for example, bigger Pharmacy robots for larger stocks of customised pharmaceuticals. Otherwise, AGVs will continue to utilise existing circulation spaces with area for storage, maintenance and recharging added throughout hospitals.

(iii) OT and Imaging: At present, open surgery remains commonly practised with less-invasive practices increasing. By 2025, nanomedicine will be driving a very different type of surgical and imaging practice. The current OT department consists of two clinical areas: (i) a surgical suite; (ii) pre&post recovery areas. Imaging consists of numerous x-ray and 3D scanning sections. Both departments are expected to continue to merge based on 'nano' technology advancements. This will extend to the point where dual modalities are no longer distinguishable but clinical sections are expected to remain as existing (see Figure 8.3).

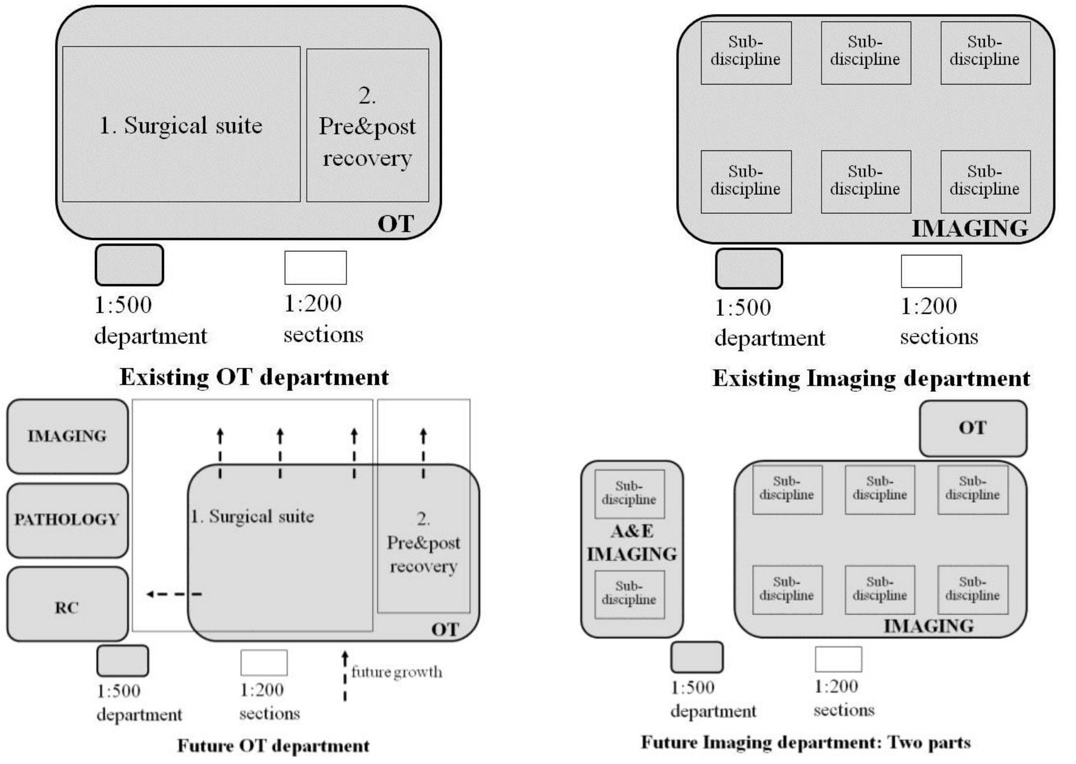


Figure 8.3 OT and Imaging: Relationship diagram for existing and long-term future.

Surgical robots are presently 1.22m x 1.22m. Findings predict technological progression will decrease the size of surgical robots, thus, reducing the area needed within OT rooms. Nevertheless, in response to more available treatments, additional OT rooms will be required, such as, cyborgization will demand operational space not currently in existence. As surgical robots reduce in size, future surgical procedures can be performed in smaller OT rooms which raises opportunities for future obsolete spaces to be adapted.

For example, this is advantageous for storing robots (7sqm) as well as creating new control and scanning rooms needed for practicing future nanomedicine. As previously addressed, the preferred location of OT departments will remain as existing while imaging rooms will relocate adjacent to OT rooms. From the perspective of this study's examined medical ETs, 1:200 spatial implications for Imaging are not available but changes at the 1:500 level are expected to be extensive. These future 1:500 medical planning issues are discussed next.

8.2.2 Discussion of 1:500 spatial implications

A number of 1:500 medical planning trends will result from the outcome of 1:200 spatial changes. This section discusses each 1:500 UAT's departmental spatial implications.

(i) A&E: A&E will remain in its current location due to its necessity for external access. This location is predominantly at ground floor level to minimise emergency circulation spaces. No 1:500 long-term impact is anticipated for A&E but spatial issues will arise during the intermediate period. This current spatial trend can be resolved through the use of adjacent soft-spaces or the ability to extend EAU space externally at ground floor levels. As a result, major 1:500 medical planning problems are not anticipated for A&E but thought must be given to the future growth of an emerging Trauma Suite. The area/sqm will counterbalance evenly with unwanted EAU space but the type of space may be incompatible as the structural design of patient room sizes is unfavourable with large surgical type rooms. Hence, after a period of departmental growth that is driven by current healthcare policies and deteriorating levels of public health, no major 1:500 spatial implications will result from incorporating medical ETs into A&E departments.

(ii) Laboratories: Laboratories will experience different spatial trends as medical ETs progress. Logically, departmental areas will be maintained should services be outsourced while on-site production will increase departmental sizes. This spatial trend will not impose upon the 1:500 medical planning of hospitals as the location of laboratories in most cases allows for external expansion at lower ground floor levels. However, unlike Pharmacy, Pathology will undergo functional changes that will shift its relationship with other departments. This development will require Pathology to relocate adjacent to OT, Imaging or RC departments. For example, surgeons' visitations to Pathology will become necessary to analyse data and specimens. As surgeons, pathologists and radiographers develop stronger working links, pathological services will become central to delivering surgical practices. Therefore, the thesis proposes the best solution is to locate Pathology adjacent to OTs to eliminate staff travel distances between hospital departments. Therefore, while Pharmacy is not expected to disrupt future 1:500 strategic medical planning, Pathology will add a new dimension to existing medical planning models.

(iii) OT and Imaging: The biggest 1:500 spatial implication will result undoubtedly from the merger of OT and Imaging departments. How this will evolve clinically will be driven by professional hierarchies which may impede against optimum medical planning solutions. Nonetheless, four 1:500 spatial trends emerge for OT and Imaging: (i) OT will not relocate; (ii) small spatial growth to OT and Imaging departments; (iii) Imaging is divided and relocated into two new areas; (iv) huge growth as a result of OT/Imaging combining for neurology based procedures. Collectively, findings indicate that a fundamental shift in 1:500 medical planning models will emerge. For example, as future Imaging becomes embedded fully in delivering surgical procedures, flows between existing scanning and OT rooms will need to be eliminated. The rational solution is to move Imaging adjacent to OTs. In doing so, the relationship between Imaging and Trauma becomes strained both physically and operationally. Therefore, the thesis suggests that two separate Imaging departments are created, of which, one will be absorbed into A&E. Alternatively, the spatial impact of Imaging facilities in OTs will pressurise an already tightly planned OT floorplate as hybrid OT/Imaging suites add 27% to OT areas while Amigo modules (530sqm) are tenfold larger than recent PFI OT rooms. Furthermore, a major reorganisation of the hospital’s 1:500 strategic medical planning will be needed to support new clinical patterns established from departmental realignments (see Figure 8.4).

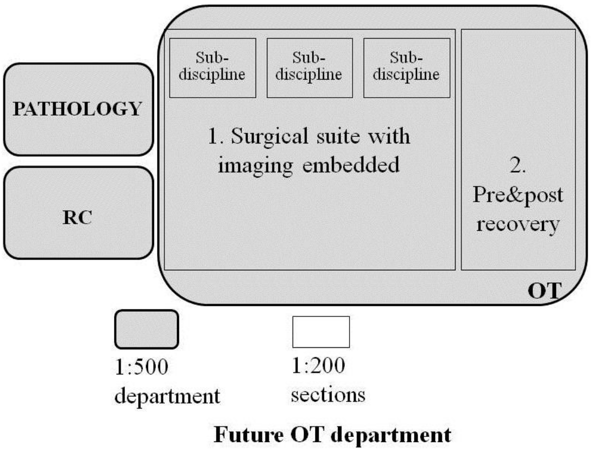


Figure 8.4 1:500 spatial implcations.

(iv) RC: Bio. Eng. is a current technology support department with no critical medical planning adjacencies. This non-clincial department exists as a small area but will evolve into a leading clinical department. By 2025, medical ETs will have transformed Bio. Eng. into a larger RC department that demands high input between surgeons, pathologists and engineers. As a result, the preference for RC is to be located adjacent to OT/Imaging suites. This new departmental dynamic will pressurise what is being visualised as a super-sized high-tech hospital unit. As a result, 1:500 future medical planning models will need to change to embrace the requirements of the new RC department as shown in Figure 8.4.

8.2.3 Discussion of 1:1000 spatial implications

This scale of design addresses the masterplanning of hospital buildings and its surroundings. Two concerns regarding 1:1000 spatial implications emerge from the last section’s 1:500 findings. The first spatial trend is the external expansion of A&E and Pharmacy departments. Opportunities to expand at ground floor levels are possible but only based on the availability of space within a hospital’s masterplan. Therefore, both departments must identify their expansion plans during initial design processes to eliminate future spatial problems particularly for urban block acute NHS hospitals. The second spatial trend is of more concern, as expansion needs to take place on upper floors. Key components driving this 1:1000 spatial trend include the relocation of Imaging, Pathology and RC departments. Collectively, they create a super high-tech floor of 2,000-2,400sqm of extra space which needs to be located preferably on existing OT floors. This scenario is a major cause for concern as the potential for expansion at OT levels is limited in many hospitals and resembles the events leading to the recent spatial failure of NHS hospitals. Discussed next, innovative solutions need to be found for expansion at the 1:1000 scale particularly for densely built acute urban block NHS hospitals.

8.3 Discussion of future medical planning solutions

This section discusses broad medical planning solutions required to deliver the thesis’ alternative vision for future urban acute hospital space. Options are formed upon long and short-term solutions: (i) short-term solutions that utilise practical applications to respond to existing architecture and spaces; (ii) long-term solutions that require innovative creative thinking that draw from a scientific understanding of the scope of ETs. Both options are underpinned by the thesis’ concern that solutions must respond to unexpected anticipations. Therefore, the thesis advocates the importance of flexibility in thinking when creating solutions for future hospital space. Consequently, the thesis presents solutions, and not a defined model, to guide medical planners' flexibility in thinking.

8.3.1 1:200 Medical planning solutions

Three key trends underpin how 1:200 hospital space will change in the future (see Table 8.1).

1. Changing size of rooms: Irregular increase and decrease in room areas
2. Addition or omission of rooms as per clinical and technological demands
3. Relocation of existing rooms.

Table 8.1 List of key trends underpinning 1:200 future hospital spatial change.

Each trend resonates 20th century hospital design principles even though medical ETs will differ radically from existing technologies. Core principles of technology's future relationship with hospital space are anticipated to continue as existing. However, different medical planning solutions will be needed to accommodate for novel medical ETs.

(i) Pod design: A more fluid approach to hospital space, that differs greatly from current rigid structures, needs to be adopted to cater for uncertainties over the next twenty years. Ongoing irregularity in changing hospital room sizes can be addressed by adopting a large open-plan strategy that can respond effectively to ever changing indeterminate spatial briefs. As at Crystal Palace, where unobstructed floor space was capable of subdiving into smaller units, Paxton's principles for creating flexible space must be embedded into future 1:200 medical planning. For example, a solution that consists of non-fixed pods situated in a large open space will respond architecturally and spatially to technology changes and present clinical unknowns. From a medical planning perspective, clinical activities with low-levels of patient intrusion should be assigned to pods as Dr. Combs suggests: 'fat zapping' (excessive fat of a person is heated away) should be conducted within a pod rather than a room (Combs, 2006: 1308). 'Pods' are not a novel concept as commercial offices and airports now commonly use this model but, with improvements in mobile and wireless medical technologies, previously unavailable clinical possibilities in less rigid environments will become available. For example, the developments in POCT equipment are precedent to proving medical ET's ability to facilitate with creating future hospital spatial flexibility. Similarly, it was shown that biotechnologies in the environment will assist with creating adaptable space by revolutionising monitoring equipment that prevents clinical space becoming obsolete overtime.

(ii) 'Universal hospital space' model: Clinical delivery evolves as new medical technologies emerge. The outcome directly influences the demand for additional or reduced hospital rooms. In fact, this study reveals that a 51.7% (average) growth in high-tech space occurred simultaneously with medical technology progression since 1950 (see section 6.6). The impact of technology is responsible for the radical compositional change in late-20th century hospital space. The spatial failure of Nucleus hospitals is testament to the outcome from post-1950s high-tech spatial expansion. A current medical planning solution aimed at resolving this problem is the 'universal hospital space' model. The main tenet of this model is to minimise the variety in size between similar hospital room types. By creating repetitive standard room sizes, adaptable space is produced to facilitate with ongoing medical activity changes. This model has been incorporated into the standardisation of certain rooms, such as, OPD consult/examination rooms but the NHS's full Activity Data Base (ADB) room list remains unexamined from the context of medical ETs and future hospital space. This status needs rectifying for the universal hospital space model to maximise its potential as a future 1:200 medical planning solution.

(iii) Adaptability is key to all 1:200 hospital medical planning solutions particularly for the relocation of existing high-tech specialist rooms. While the universal space model attempts to limit variety amongst similar hospital room types, this approach may not be transferred as easily between different types of rooms. For example, in response to future surgical practices, CT scanning rooms of 36sqm will need to move to the OT department. As OT rooms are 55sqm minimum, CT rooms can relocate to within existing column free spaces. Leftover space of 19sqm can be replanned to create new control rooms and biotechnology testing areas. Alternatively, relocating a CT room to the new Trauma Suite will experience major difficulties as existing EAU space consists of rooms structured upon 16.5sqm and 4.5sqm. This medical planning problem has been detrimental to adapting previous NHS hospitals. Problems are driven by fixed hospital building elements of walls, columns and services. New technologies improved by nanotechnology progression are anticipated to increase the structural strength of architectural materials. New inventions will allow for wider column spans and decreased slab depths that will alleviate existing medical planning restrictions. These architectural technologies will instigate a new medical planning revolution similar to early-20th century hospital design after inboard architectural services and fluoroscence lighting were introduced (see section 4.3.2). These ETs are longer term solutions but, meanwhile, ‘outside-the-box’ thinking for architectural technologies needs immediate attention. New innovative architectural technologies need to be founded upon theoretical concepts that walls, floors and ceilings are defined as physical membranes. A precedent for radical change in the thought process for creating flexible hospital design solutions is BMW’s 2008 ‘Gina Light Visionary Model’ (Jury, 2010:24). The car model is made of a seamless fabric that stretches over aluminium wire structures and contorts into any desired state of form quickly. This conceptual breakthrough in car manufacturing challenges the essence of conventional hospital building thinking. Theoretically, the thesis believes the application of BMW's Gina principles would create new architectural technologies that allow for the cellularisation of hospital activities to become spatially and architecturally adaptable. A second 'outside-the-box' example uses App technology to challenge the existence of non-functional space. For example, App technology can identify patients to clinical administrators as they enter into a hospital. This technology omits the need for patients to report physically to a receptionist. Admission details are sent to patients' phones which direct them to their area of clinical activity, thus, reducing the cost for non-clinical space for waiting and registering activities. Furthermore, deeper medical planning consequences are driven by App technology's independence from a hospital's fabric. Upgrades or new replacements of App technologies can be undertaken without effecting space or building fabric. This ET is crucial to evolving and benefiting the relationship between hospital space and technology to a point where some medical technologies no longer rely upon hospital space to function. This study emphasises the importance of this emerging relationship as essential to underpinning the principles of a new medical planning model. The essence of this tenet is: hospital space should be formed upon the quality environments instead of technological or architectural components that dictate the size of future hospital spaces.

8.3.2 1:500 Medical planning solutions

Flexible design solutions underpin the success of 1:500 medical planning strategies. In response, this study proposes a new medical planning concept which is configured diagrammatically in Figures 8.5-8. This solution is based upon two principle design elements at the 1:500 scale: (i) ‘departmental’ block arrangement; (ii) arrangement of access and flows.

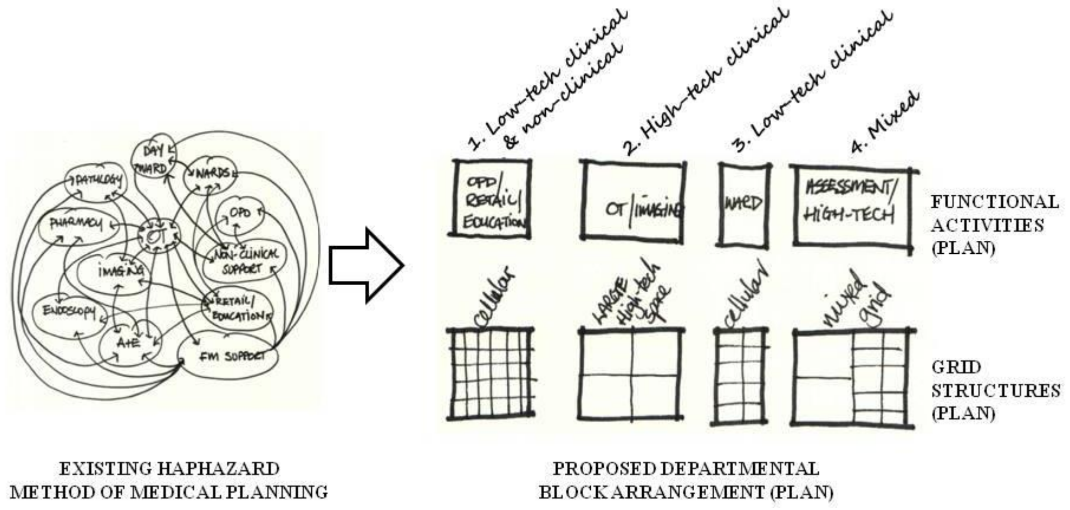


Figure 8.5 Alternative 1:500 future medical planning thinking.

(i) Clinical hierarchies dictate the present existence of hospital departmental boundaries. This 20th century 1:500 spatial approach needs rectifying for game changing progress to occur in medical planning. Change is growing momentum through the merging of surgical and imaging modalities. Evolving principles in cross-utilisation are key to dissolving the rigidity of other departmental boundaries. On this basis, the thesis proposes a solution that standardises the arrangement of ‘1:500 departments’ in plan and section rather than the present freerange manner of organisation (see Figure 8.5). Conceptually, each floor template consists of a pattern that spatially blocks clinical and non-clinical activities together but allows each block to be formed architecturally by architects as they wish. Fundamentally, this strategy is underpinned by a standardised structural design that assigns each block with a column layout favourable to its functional activities. This strategic layout is repeated vertically to create spatial adaptability on and between floors to minimise future medical planning problems as clinical demands evolve. This solution organises each floor to become a specific unit of clinical excellence which locates similar functional activities vertically for clinical and staff efficiencies. For example, an emergency floor's large high-tech spaces would be designated to Trauma Suites with open lounge areas for assessment and treatments and recovery cabin areas for long-term patient observation. Alternatively, the same standard floor template would be used for an elective OT/Imaging Suite. This floor would contain similar high-tech spaces for operations and lounge areas for pre&post operative care (see Figure 8.6).

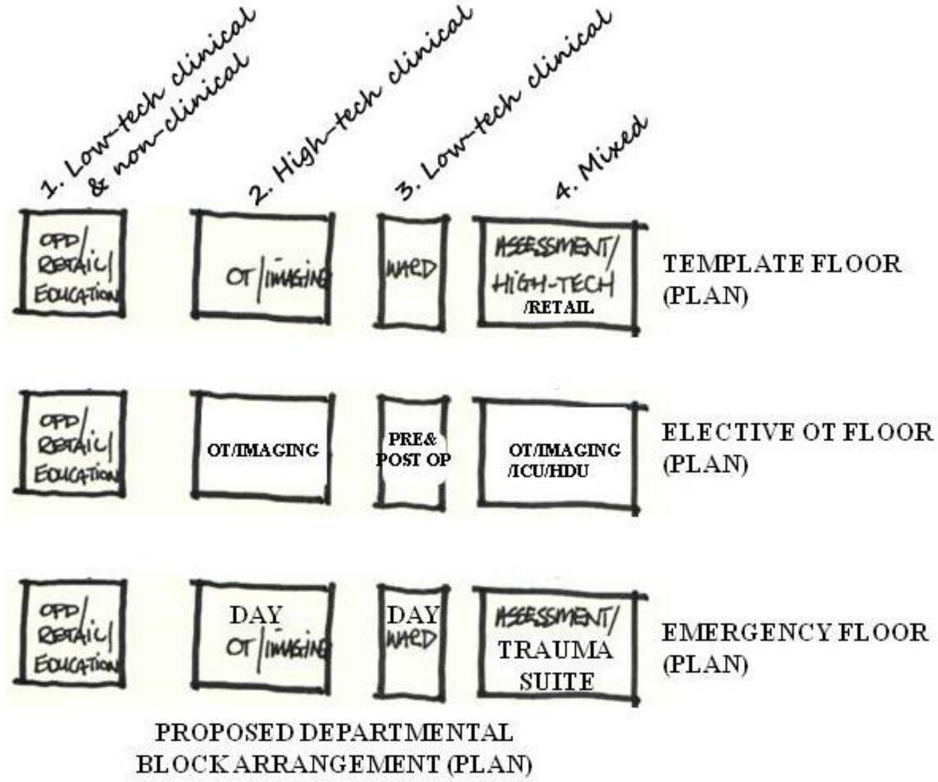


Figure 8.6 Alternative 1:500 future medical planning solution: Access points

(ii) The thesis acknowledges medical ETs will change the movement of people, goods, data and energy around hospitals. Changes to flows at the 1:500 design scale will result from re-arranged departments. However, basic principles of horizontal and vertical circulation will remain for people and goods. Alternatively, new methods for transporting data and energy will emerge to offer opportunities for creating less rigid environments. The approach to addressing change will be focused on reducing travel distances and unnecessary routes that are driven by the existing multitude of desired departmental adjacencies. Therefore, the strategic organisation of movement in this thesis' 1:500 medical planning proposal is predominantly: horizontal for patients; vertical for staff and goods (see Figure 8.7A-C).

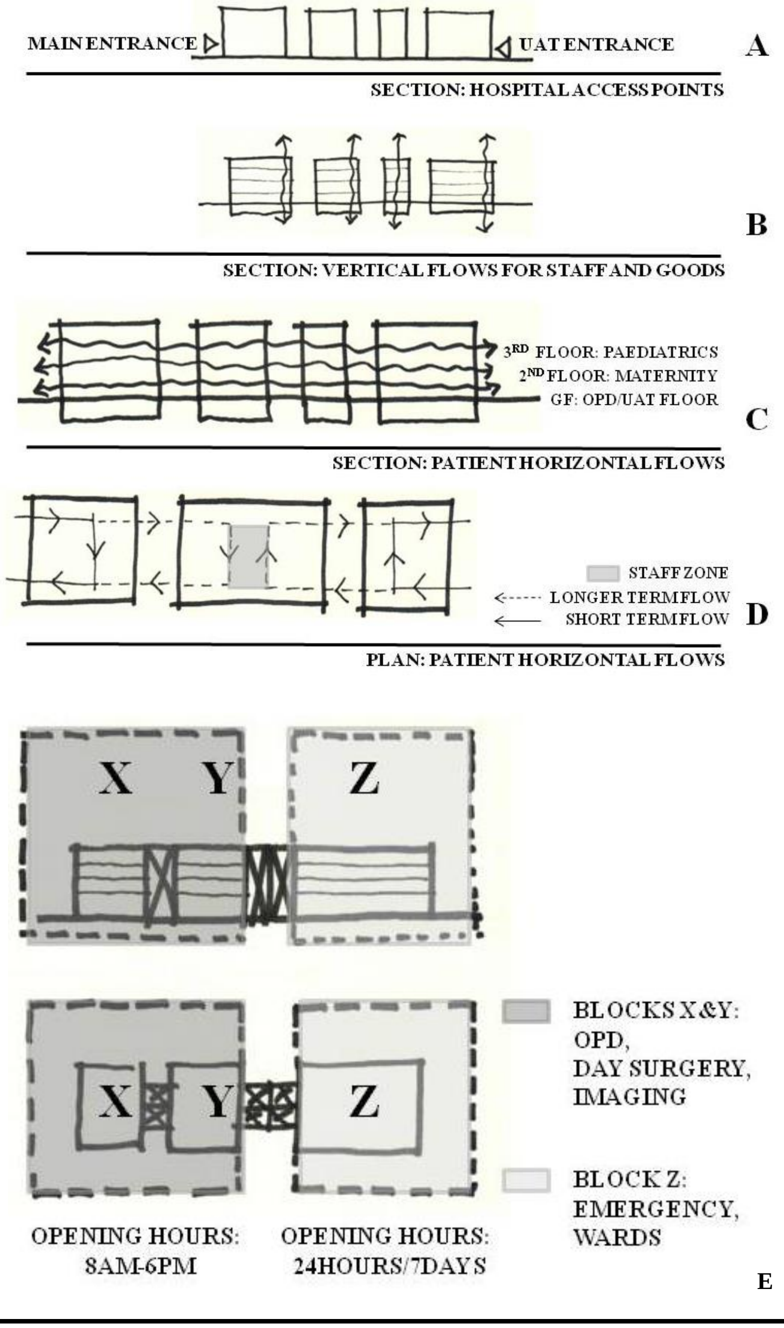


Figure 8.7 A-D Left: Alternative 1:500 future medical planning solution: Access points and flows. **Figure 8.7E Right:** Plan and section of alternative 1:500 future medical planning block solution.

A core factor driving this concept is the reduction of in-patient and staff floor-to-floor transfers which, in addition to minimising expensive circulation space, is expressed constantly as a top design problem by all hospital staff. This factor focuses on enhancing patients' privacy as well as improving hospital operations, as lifts in NHS hospitals are infamous for being maintained poorly. Therefore, patient dignity and staff efficiencies will be maximised by assigning multi-disciplinary medical teams to each floor, as the largest number of daily staff flows is between clinics, theatres and wards. Therefore, time wasted waiting for lifts is eliminated when staff are assigned to a single floor. Alternatively, less frequent travel journeys, such as, weekly departmental clinical reviews can be undertaken between floors by able clinicians to optimise spatial use. This alternative arrangement for connectivity creates closer links between clinical activities that can flex functionally into similar adjacent spaces or ‘departments’ to maximise space outside of operational hours (see Figure 8.7D). This utilisation of space is dedicated to reducing staff and patient flows unlike existing 1:500 departmental models that encourage excessive interdepartmental travel distances. Hence, the thesis advocates this design principle as central to the success of future hospital medical planning and drives the concept depicted in Figures 8.7D-E.

Through the organisation of space, two sustainable solutions are included in the proposed medical planning diagramme. The first relates to the standardisation of floor-to-ceiling heights. Normally, this model is considered wasteful but this study argues that the standardisation of floor heights is a more sophisticated long-term sustainable solution, as it eliminates restrictions when rearranging space as demands evolve. The second sustainable solution concerns the reduction of energy use. The proposed medical planning concept is designed to shut down a part, whole floor or full block rather than close areas in a disjointed manner. This design proposal closes functional space as well as all associated non-functional areas, such as, corridors and staff areas. This strategy contrasts with current policies that close space sporadically without reviewing cost savings from a fully operational perspective (see Figure 8.7E). Furthermore, Blocks X and Y are closed down between 6pm-6am daily. Lighting, air-conditioning and heating are reduced to a minimum to create an energy saving solution.

8.3.3 1:1000 Medical planning solutions

The principle of flexibility is extended further at the 1:1000 scale but present spatial ‘outside-of-the-box’ solutions are not being executed to prevent expensive hospitals from becoming obsolete. For example, if a department cannot expand spatially, services are relocated off-site which potentially leads to a very expensive whole hospital refurbishment. More significantly, a redesign risks weakening an efficient hospital strategic medical planning which is reflected in many older NHS hospitals, such as, Poole General Hospital. While technology has been a driver of process change within hospital environments, unlike airport or office typologies, hospitals have not benefited from a revolution in typology development. However, the thesis is not of the view that hospital typologies should replicate airports. Hospitals are dissimilar in nature by their social and psychological human interactions. Nevertheless, basic design principles from this precedent maybe adapted accordingly. Three 1:1000 medical planning concepts are presented to invoke exploration of maximising the flexibility of hospital typologies.

The first medical planning solution draws upon mat-building principles, which characterise an urban typology that is able to change during construction, refurbishment and overall existence. However, the mat-building was tested unsuccessfully as a hospital model in NHS Nucleus hospitals (see section 4.3.4). This outcome does not exclude the mat-building as an appropriate precedent for future hospital design. Instead, the thesis argues that the NHS’s interpretation and delivery of the mat-building was flawed. Theoretically, the mat-building typology sustains against future spatial change. In the face of medical ETs, where a high degree of future spatial evolution is expected, this study advocates the mat-building model as a valuable precedent for creating a future new urban acute hospital design model. A basic principle of the mat-building typology is that the inner workings of buildings interface with their surrounding urban fabrics. Or more precisely, as architect Stan Allen argues:

> A site strategy that lets the city flow through the project (Allen, 2001:121).

One architectural feature that delivers this principle is a unifying roof. This feature has been disregarded in recent hospital designs for financial and mechanical plant reasons. Considering the long-term flexibility of, and importance of UAS in hospitals, this study proposes the use of unifying roofs is worthy of exploration for individual hospitals. In particular, the use of lightweight prefabrication, that incorporates principles from the BMW's Gina model, offer potential future expansion space currently under utilised by NHS hospitals (see Figure 8.8A).

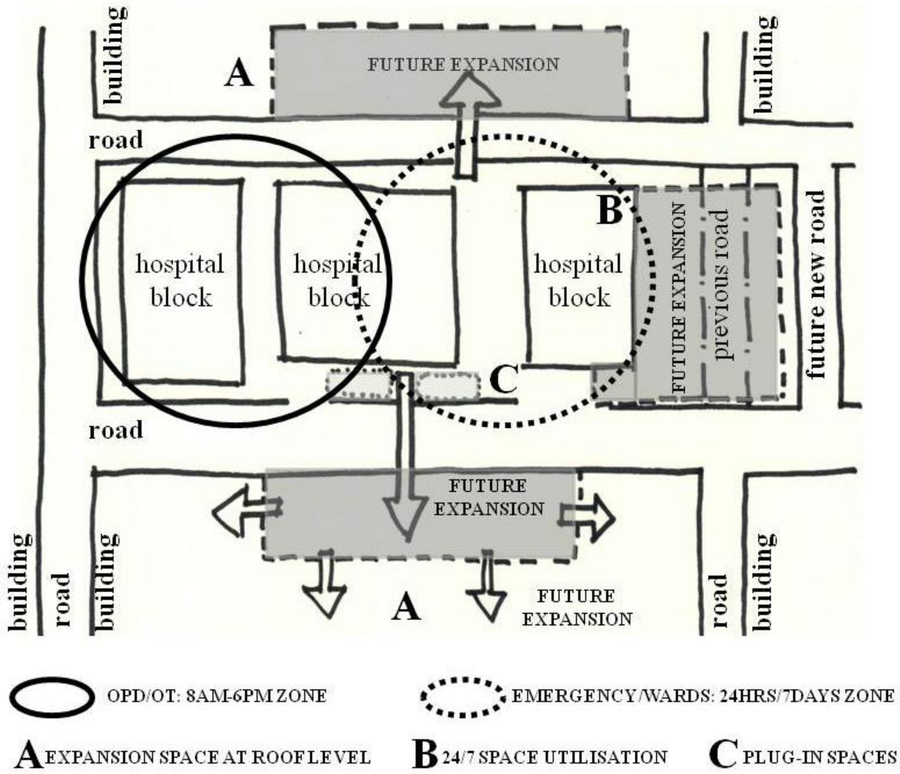


Figure 8.8 Alternative 1:1000 future medical planning solution: Expansion plans.

The second solution regards the maximisation of hospital space utilisation. Driven by hospital business models, the blurring of departmental boundaries is underpinned by the mat-building principle of interconnectivity at a typology scale. At present, the capital potential of some hospital spaces is not being fulfilled. These include Kitchen and Dining areas which are closed broadly between 7pm-6am. By rearranging departments to cater for external public access, services can operate longer hours to capitalise on this 1:1000 scale urban acute hospital strategy (see Figure 8.8B). This concept can be utilised similarly to benefit greater incomes for Pharmacy, Pathology and Imaging services. Operational policies will need to be updated for this spatial strategy to be implemented successfully in NHS urban acute hospitals.

The third option embraces the wider urban environment as a strategy for spatial growth where clinical activities are no longer confined within a hospital’s building. As hospitals are organic buildings, constantly in motion and never complete, the current nature of hospitals as distinct architectural objects is contradictory and detrimental. From an architectural perspective, present hospital design resonates architect Aldo van Eyck’s argument that architecture’s recent fascination with form is completely inappropriate (Neville, 2008:3). Further to this belief, van Eyck argues that a shift towards the importance of integrated relationships between buildings rather than the buildings themselves badly needs reforming. This thesis concurs with this principle and believes that opportunities to be innovative arose when NHS estate ownership was transformed under the PFI process. However, NHS hospital space has not maximised the formation of new spatial relationships at the 1:1000 scale. For example, the creation of new medical spaces outside hospitals exists in the form of mobile trucks parked near hospitals. Taking this concept onboard, mobile structures offer alternative spatial solutions for much needed flexible accommodation when required to respond to ongoing technological and medical practice changes. Therefore, space must always be allocated within a hospital’s strategic masterplan for both permanent and temporary 1:1000 spatial expansion. Drawing on Renkoi’s principles for routes, flows and relationships, a wide range of opportunities are available for expanding urban hospitals. Trains, trucks, boats and inflatable pods, that connect physically into a hospital's medical planning masterplan and buildings, are all potential spatial options worth considering for flexibility at the 1:1000 medical planning solutions (see Figure 8.8C).

8.4 Clinical scenarios for future urban acute NHS hospitals

From scenario logics identified in section 3.8, three plausible scenarios are generated to provide a visualisation for future hospital space. Chapter 7's identified spatial and medical planning trends inform this section's scenarios which depict hospital space in existing NHS hospitals in ten years time. Each scenario is self-contained offering alternative futures for NHS hospital space based on key variables, such as, economic and technology growth and the NHS's ability to adopt medical ETs. A different typology is assigned to each scenario to contextualise the range of possible spatial outcomes. These are: campus type model (St. Thomas'); 'matchbox-on-a-muffin' model (UCLH); hybrid hospital model (RLH). Each scenario originates from a single event described in Table 8.2.

In 2025, global warming continues to create adverse weather conditions. On one occasion, blearing sunlight during a March heatwave in London causes a major car incident. A three way collision occurs between an elderly pedestrian (Sam), a 24 year old male cyborg (Jason) in a robotic car and a healthy 57 year old female (Fiona) in a manual 1995 Toyota Corolla. Fiona is injured critically and air lifted by HEMS paramedics to the RLH's A&E Trauma Suite. Jason is stabilised at the scene before being transferred by ambulance to St. Thomas' A&E department. Sam, believing he is unharmed physically, continues on his journey. He feels unwell later and travels by automated bus to UCLH's Urgent Acute Centre for assessment.

Table 8.2 Single event in 2025 that generates thesis scenarios.

8.4.1 Scenario No.1: High medical ET growth with full adoption by the NHS

Responding to the robotic car’s distress code, the first attending paramedic arrives by motorbicycle to the accident within three minutes. The paramedic, David, attends to the most critical patient first who is not wearing any ‘smart’ medical technology. David uses a small finger print scanner to access Fiona’s electronic medical record (EMR). Using hand-held POCT equipment, David analyses Fiona’s bloods, temperature and heart rate while a hand-held ultrasound diagnoses Fiona with head and spinal injuries. This requires major trauma surgery which David relays vocally to the NHS’s Emergency Data Centre (EDC) via ubiquitous uPad technology embedded in his jacket. The EDC is a specialist UAT service based in Edinburgh that organises the maximisation of sparse specialist UAT staff and knowledge. The EDC dispatches a HEMS helicopter to transport Fiona to the RLH. While being transferred, air paramedics take further blood tests with LOC technology for clinical analyses. These, and all of Fiona’s vital signs, are monitored within the helicopter, at the hospital and by the EDC. At the RLH, a neurological multi-disciplinary team has been mobilised to discuss Fiona’s data and create a medication treatment plan. Fiona’s custom-made-drugs are approved of jointly whereby Aseptic Suite staff are notified immediately. Fiona’s custom-made-drugs are produced on-site and delivered by pneumatic tube to the Trauma Suite prior to her nano-surgical procedure. Before arrival, Fiona goes into cardiac arrest and needs resuscitation. Airborne paramedics stabilise Fiona with assistance from EDC emergency surgeons via telesurgery.

At the RLH, the UAT team have prepared a hybrid OT room in the A&E’s Trauma Suite where all of Fiona’s medical data is projected onto virtual information walls. On arrival, Fiona is transferred directly into the hybrid OT room to be CT scanned by the waiting neurological imaging technologist. Real-time results allow for a final confirmation for Fiona’s surgical plan. Information technologists and radiographers corroborate with the neuro-surgeons’ decision to operate for fluid-on-the-brain first. The biomedical engineer has been party to discussions to confirm what tools are necessary for using the latest *da Vinci* surgical robot. The robot is positioned to drill through Fiona’s scalp after her non-invasive imaging is completed. The robot’s procedure is overseen by surgeons in an adjoining control room. On completion, the surgeon returns to the OT room to take swabs for rapid analysis. Samples are tested in an adjacent space outside the operating room where results are emailed directly onto the information wall wirelessly. A plastic surgeon completes the procedure by re-stitching open wounds. Simultaneously, preparations for Fiona’s spinal injuries are taking place by the nanosurgeon. A solution of formulated nanorobts is injected to target Fiona’s spinal injuries internally. The CT scanner is moved back into position to scan for the nanorobots’ location and completion of works. Fiona is transferred to the ICU after her successful operation.

Table 8.3 Patient scenario No.1: Technological and medical proceses.

By 2025, the RLH remains at its original location in London. This hybrid hospital typology has been able to expand successfully based on its available UAS medical planning strategy. Adaptability, however, has proven difficult and expensive due to the numerous clinical and technology changes that have emerged since the new hospital opened in 2012. Specifically, problems arose on the 3rd and 4th floors of the PFI urban block where replanning for new hybrid OT rooms became impossible without reducing surgical activity. While ‘swallowing-the-surgeon’ technology required no extra space for equipment, additional imaging modalities and adjoining control rooms required twice the original size of OT rooms. Expansion was achieved through external links across to an adjacent site’s building where unwanted space was utilised for pre&post operative and office areas at the top two floor levels.

The Main Imaging department located at Level 1 has adapted well due to the original medical planning strategy to completely separate emergency radiography. Satellite Imaging at Ground Floor was located originally adjacent to A&E which contained large 9x9m spans that were compatible with the incoming hybrid OT model. Subsequently, when the A&E department was renovated to respond to new healthcare policies and medical ETs, its medical planning proved easily adaptable due to the existence of adjacent imaging rooms. More significantly was the importance of the new Trauma Suite model which transformed the patient trauma care flow. Undesirable travel distances to imaging and emergency OT rooms on other floors were eliminated.

The exclusion of Pathology in the 2012 PFI block proved beneficial in 2019 when the department needed to expand substantially in response to biotechnology expansion. A completely new campus building was rebuilt with pathological areas, requiring operational adjacencies with the OT Suite (Level 3), were linked horizontally into the PFI block's 3rd level. Alternatively, Satellite Pharmacy's location at Level 5 in the PFI block did not allow for spatial expansion but Pharmacy remained as a separate building on the RLH's campus. This medical planning decision allowed for on-site pharmacy production to continue as well as expand spatially in response to radical pharmaceutical changes that emerged by 2020 when custom-made-drugs became available.

Space for computers and monitors was omitted post-2018 as IT interfaces became technologically visual, haptic and voice operated. Services, power and gases remained fixed in rooms associated with this patient scenario due to the explicit complexity of future neurological surgical practice. In general, the RLH's strategic medical planning remained sustainable as a hybrid campus model with respect to high technology growth and the NHS's full adoption of medical ETs.

8.4.2 Scenario No.2: Slow medical ET growth but full adoption by the NHS

Clare, the second attending paramedic, arrived by ambulance within six minutes of the event. She has been monitoring David and the EDC’s progress report on her hand-held personal digital assistant (PDA). On arrival, Clare immediately attends to Jason who is wearing a medical belt. She is able to automatically access and download all of his EMRs. This time saving in prognosis determines Jason as requiring no clinical tests for abnormalities. Clare uses her hand-held equipment to ultrasound and take Jasons’s measurements in real-time. Jason is diagnosed with a shattered humerous which needs emergency orthopaedic surgery and reconstructive surgery to reattach his bionic hand to his left radius. Clare’s prognosis is delivered verbally to the EDC via Clare’s smart jacket. She is informed that Jason must be transferred to London’s St. Thomas’ hospital. Before departing, Clare stabilizes Jason with an intravenous infusion for loss of fluids and blood while nanotechnology bandages, infused with antibiotics and painkillers, control infection. Enroute, Clare administers a dose of nanopharmaceuticals while Jason’s vital signs are monitored using a smart blanket. The EDC and multidisciplinary team are also monitoring Jason’s status in case he needs a blood transfusion. The Blood Bank and Pharmacy are alerted upon which Jason’s DNA information is activated to produce custom-made-drugs for his medication plan and customised blood packs for surgery. Meanwhile, Clare activates an App within Jason’s medical belt that notifies his next of kin of events and his transfer to St. Thomas’ A&E department.

A multi-disciplinary team has been mobilised at St. Thomas’ by the EDC. Part of this team is Birmingham’s RC department, as only one exists within the NHS. A recorded video of events from Jason’s automatic car has been issued to all team members. A joint assessment of events via Skype leads to a surgical treatment plan for Jason. As a result, the A&E trauma team are waiting in St. Thomas’ East Block to admit Jason for a full body MRI scan. Thereafter, he is transferred to an orthopaedic OT room located on the Lambeth Wing's 2nd floor. Jason's bionic hand is taken to be examined and recalibrated by biomedical engineers. As 'swallowing the surgeon' technology is limited by 2025, *iSnake* robots are used to repair Jason's shattered humerous. Therapeutic cloning will hasten the healing of his humerous by using biotechnology scaffolds. Both medical ETs required no additional space allowing St. Thomas' to evolve their orthopaedic surgical practices. Once completed, Jason is transferred to the medical ship where the neuro-robotics surgical team is waiting. The Birmingham specialist team are notified via telesurgery where they commence the reattachment of the cyborgs hand via the latest *da Vinci* robot model. The neuro-surgeon operates the robot in Birmingham supported by orthopaedic surgeons and neuro-nurses at St. Thomas'. To begin, Jason's full body scan is projected onto his body which remains during his two hour bionic operation. Numerous CT scans are taken during the procedure to check Jason's thought controlled prosthetic has been attached successfully. On completion, the team in Birmingham stepdown to prepare for another telesurgery operation in Carlise. At St. Thomas', Jason is moved to the East Wing's 1st floor ICU department once his operations are completed.

Table 8.4 Patient scenario No.2: Technological and medical processes.

As a campus typology, St. Thomas' remains at its current location in 2025. While medical ETs have been slow to materialise, St. Thomas' continues to be a forerunner in adopting new technologies. Substantial quantities of UAS have allowed for spatial adaptability in the hospital. Two innovative flexible design solutions have responded to technological change. The first innovative solution took advantage of the adjacent Thames River to extend St. Thomas' OT/Imaging department. This necessary expansion in 2019 reflected the 1961 redirection of Lambeth Palace Road which gained extra land for St. Thomas' redevelopment programme. A medical ship harboured parellel to the

South Wing is a temporary solution for the rapidly evolving Imaging department which was fragmented at basement and ground floor levels[2] and undergoing an uncertain time of technological change. UAS (2,000sqm), located below Imaging in the Lambeth Wing's 1st floor, was adaptable but additional imaging space to support changing medical practices was deemed unsustainable. An analysis of the 19th century South Wing block determined that continuous renovation would be imminently more disruptive than beneficial. Therefore, until medical ETs became more established and compatible with existing hospital spaces, a medical ship solution was justified as a pragmatic short-term spatial strategy. The second innovative solution was the relocation of St. Thomas' pathology research facilities which did not require direct medical planning adjacencies with any hospital departments. A new cheaper building was constructed on an adjacent site and accessed by a linkbridge over Lambeth Palace Road. The medical planning outcome allowed three floors (2nd, 4th, 5th) of the North Wing to become available for renovation. This was assigned to therapeutic cloning and molecular engineering expansion. Additionally, this evolving department was located with new adjacencies to the emerging OT/Imaging suite in mind.

The remaining UAT departments have adapted well in the face of slow nanotechnology growth. Pharmacy remains located on the South Wing's 2nd floor where space for a Pharmacy robot was facilitated through the hospital's new efficient strategy for storing drugs. New drug deliveries and custom-made-drugs have not emerged fully yet but UAS has been allocated adjacent for future Aseptic Suite expansion. Similarly, the OT department remains unchanged, as future surgical robots are smaller than existing machines. No extra space was demanded for in the OT department but incoming neuro-bionic technologies will change surgical, imaging and pathological relationships. This

---

[2] Basement level – South Wing (small) and North Wing. 1st floor - Lambeth Wing (2010).

future scenario was a key driver to relocating Pathology research laboratories as a new phase of replanning the OT department awaits new medical ETs. Bio. Eng. remains a small unit but plans to establish a new RC department are underway in the South Wing adjacent to Neurology OPD, Rehabilitation and OTs. After a short-term surge in additional A&E cabins, the pressure on space in the East Wing’s GF A&E department has receded finally. The use of LOC, POCT and smart technologies as well as early forms of custom-made-drugs, have reduced the numbers of chronically ill patients attending St. Thomas’ A&E. As a result, A&E triage, observation and treatment areas have been redesigned to be more openly planned and less rigid. Pods, that were adaptable to within existing column structures, have created a supply of sustainable spaces. However, the hybrid OT room model has not replaced existing trauma bays explaining Jason’s inappropriate transfers to other departments for emergency surgery. New rooms for monitoring patient signals have been easily adapted from unused EAU bedrooms while human assisted robots have gained a presence in St. Thomas’ without impacting on hospital space.

Generally, St. Thomas’ has fully adopted the slow growth of medical ETs and remains sustainable as a hospital campus typology. Space for computers and monitors were only omitted in 2023 while services, power and gases remained fixed in most hospital rooms. Developments in front-of-house public areas are progressing steadily to be less rigid and user friendly. All teaching and administration facilities have been relocated to a new building across Lambeth Palace Road. This move and the medical ship solution has allowed for all buildings in the gardens to be removed, reinstating Nightingale’s original holistic environment for St. Thomas’ hospital.

8.4.3 Scenario No.3: High medical ET growth but full adoption is not realised by the NHS

Sam was checked medically by David, the paramedic, at the accident scene. Sam continues on his journey as no visible symptoms were diagnosed. The March heat-wave however brings on an acute asthma attack as his LIC chip has become dislodged during the incident. Sam, a registered asthma and diabetic patient, also wears clothes that monitor his weight and respiratory functions. A sensor alerts Sam’s general practitioner (GP) who Skypes Sam on his smart-watch telling Sam he needs to go to a ‘virtual clinic’ for examination. At his local shopping centre, Sam logs on to take an x-ray of the LIC chip in his arm within an A&E booth (1x1m). The x-ray is sent to the EDC where results are emailed immediately to Sam’s GP. The GP needs to gather additional information and Skypes Sam in the A&E booth. Its larger screen, fingerprint and eye recognition technology allow for Sam to be assessed by the GP. The GP needs to monitor Sam’s temperature, heart and breathing rates which are performed by downloading software into Sam’s smart clothing wirelessly. On reading Sam’s vital signs, his GP tells him to go to hospital for clinical observation. Sam is notified that delays will occur at his preferred hospital but admittance to UCLH will be immediate. Sam confirms he will present himself at UCLH and takes an autobus while being monitored continually through his medical jacket. Sam also verbally records how he feels through a speech recognition programme embedded in his jacket.

An urgent-acute medical team have been notified to commence preparations for Sam’s admission to UCLH’s A&E. As Sam walks through the A&E entrance, his jacket’s App acknowledges his arrival to the medical team. An admissions nurse goes to meet him at Reception to discuss Sam’s deteriorating condition. Using a tablet, Sam’s EMR is uploaded but unfortunately today’s events have not been updated. UCLH’s older technologies are incompatible with the NHS's current EMR system which causes repeated data gathering and inefficient time delays as a result of incohesive information. Therefore, the admissions nurse needs to input data of events and how Sam is physically feeling. By 2025, waiting times have been reduced to 5-10 minutes at certain NHS hospitals but UCLH's lack of cutting-edge technology drives waiting times up to eight hours. Sam waits for information to be distributed internally before being assigned to an observation cabin. As Sam walks into his cabin, his consultant, Eva, is notified of Sam's readiness for examination via App technology. Shortly afterwards, a phlebotomist arrives to take Sam's bloods which are sent off to be analysed off-site. Vital signs are measured from Sam's clothing but remain viewed visually in the cabin by signal monitors. On entering Sam's cabin, the emergency consultant, Eva, is registered by Apps as attending to Sam. Eva accesses Sam's new EMR via her PDA as video wallpaper or ubiquitous technologies do not exist. Eva needs to confirm that Sam's LIC chip has not been dislodged or damaged. While the initial scan in the A&E booth demonstrated abnormalities, this information is currently not available for making decisions. Sam is sent for an x-ray to the department on the floor below but waits for two hours in his cabin due to limited imaging technologies. Meanwhile, Sam is administered drugs to stabilize his chronic asthma attack. After his scan, further delays are experienced for Sam's pathology diagnoses as well as the medical team's unavailability to analyse test results. Sam waits another hour for Eva to assess Sam's medical test results which confirm he needs minor surgery to relocate his LIC chip. A 15-minute procedure is done in his cabin where on completion Sam's vital signs return to normal. Within the hour, Sam leaves via the A&E entrance where his 'smart' clothes record his discharge.

Table 8.5 Patient scenario No.3: Technological and medical processes.

By 2025, UCLH’s urban block typology has struggled constantly with spatial change. Historically, this hospital has relocated several times and may witness the same strategy being adopted in the future. Challenges include the need to respond to new medical planning adjacencies and spatial growth of all high-tech departments. The outcome has led to severely pressurised hospital services being delivered in inflexible outdated spatial environments. For example, the non-existence of an adjacency between Pathology and OT at Level 3 disallows for nanosurgical practices to be introduced, as space for an on-site Pathology is not available at UCLH. Similarly, Imaging needs to grow at the Basement Level but extra space is unavailable. Free space on an adjacent site could be utilised if existing city planning infrastructures would allow for an underground system. Both spatial problems could be addressed at the 1:1000 scale rather than inflict burdensome capital costs of constructing a whole new hospital building on an alternative site. One optional medical planning solution to UCLH’s problem is the construction of a building on an adjacent site that uses only one-two floors as part of its hospital’s business model. This option would rent out non-clinical spaces as viable commercial units on other floors. This innovative healthcare policy would create new urban relationships that fulfil mat-building principles of urban connectivity. Driving this option is an ever-evolving typology that demands fluidity of its architectural boundaries to become sustainable as a hospital building within an urban context. For example, the typology model for retail shopping centres is ground floor and first floor accommodation. Opportunities for healthcare facilities above retail units include day surgery, OPD clinics and basic diagnostics. This proposal is driven by easy-to-use medical ETs as well as available off-peak parking spaces, which offer options to de-pressurise NHS services but, more importantly, expensive space at UCLH.

The 1:500 departmental planning of UCLH remains unchanged due to its restrictive defined urban block form, core design and structural grid layout. As a result, the scope for major change at 1:500 has been limited since its opening in 2005. For example, original policies for off-site production were beneficial for Pharmacy and Pathology. However, future medical practice relies heavily on laboratory services which, as an off-site service, reduces the efficiency of future healthcare delivery. To resolve this issue demands laboratory services to be relocated on-site which UCLH is incapable of catering for spatially. This status reflects the restrictive nature of future urban block hospital typologies and determines why UCLH's 1:500 medical planning remains inflexibly static.

Adaptability has been more successful at the 1:200 scale as a substantial amount of UAS was incorporated originally. The 3,000sqm of embedded UAS caters for the decanting of one large department at a time. This policy is the fundamental reason why UCLH remains functional in 2025. However, additional space required for technology changes at UCLH has been limiting. For example, the spatial impact of incorporating an Amigo suite (530sqm) model was identified as impossible at UCLH in 2018. Fortunately, smaller future surgical robots have allowed certain medical ETs to be fully utilised within existing OT rooms with surplus space redesigned for necessary new control rooms.

In 2019, UCLH was downgraded from a major trauma acute hospital to an urgent-acute centre that caters for old medical practices with 'out-of-date' technologies. This strategy was damaging to UCLH's reputation as its perception by the medical profession and public was undermined as a centre of excellence with cutting-edge medical practices and technologies. This outcome was driven by the overbuilding of A&E assessment rooms in the 2010s which created a surplus of unnecessary future patient rooms at ground floor. These rooms, still packed with monitors and screens, were not as easily adapted structurally. Therefore, a policy was established to maintain old technologies and practices to utilise UCLH’s existing A&E cabins. As a result, UCLH’s original 3,000sqm A&E layout remains as a 20th century medical planning model with cellular rooms and long intimidating corridors still in existence by 2025. In contrast, other NHS hospitals contain ‘state-of-the-art’ A&E layouts which consist of large open-planned spaces that reflect a spatial model similar to Paxton’s Crystal Palace. Spatial division for functional differences has been achieved through ubiquitous technologies that are capable of structuring membrane walls as physical dividers. Interior imagery is downloaded by App technology from patients’ phones similar to the primitive forms which appeared in the design of OT/ICU internal room glazing in 2012. Benefits from this product’s development with nanotechnology have been utilised greatly by all medical planners in the future. Overall, the ongoing challenge of UCLH’s spatial restrictions will remain constant until 2040. This status will be driven by: its PFI contract; inflexible urban block typology; lack of innovative solutions to deal with restrictive spatial parameters. For example, the use of human assisted robots was introduced into UCLH in 2020. Increased use, however, was restricted due to an inability to widen hospital corridors.

8.5 Assessment of flexible design solutions through PFI NHS hospitals

The durability of PFI NHS hospitals is examined to assess the need for flexible hospital design solutions. Two medical planning areas are considered in this assessment: (i) embedded architectural principles; (ii) numerous spatial issues.

(i) The first medical planning area involves three architectural principles revealed as essential for achieving sustainable acute hospitals (see Table 8.6). Assessing the presence of these architectural tenets within each hospital case study examined assists with determining the resilience of PFI NHS acute hospitals.

Three architectural principles for durable hospitals	
No.1	Incorporation of a UAS strategy
No.2	Spatial flexibility and adaptability at alternative scales from 1:200-1000
No.3	Avoid the NHS's 1980-2000s delivery type of Nucleus typologies.

Table 8.6 List of architectural principles to determine the durability of PFI hospitals.

A campus styled typology was identified as a sustainable medical planning solution for urban acute hospitals (see Chapter 6). The implementation of UAS strategies was determined as central to the success of this typology. On this basis, this study expects the RLH and St. Thomas' to sustain their existing campus typologies based on both hospitals' substantial UAS for future decanting and spatial renovations. In contrast, urban block typologies have been unsuccessful historically, particularly between 1950-2010 where the vast growth in new high-tech hospital space (21,900sqm average) caused detrimental spatial outcomes (see section 6.6). In continuing this trend, this study determines that UCLH and RLH PFI hospitals will outgrow their buildings within the next twenty years based on inadequate UAS for spatial alterations. This projection is supported by large proportions of continuously changing high-tech hospital space existing within both urban block acute hospital buildings. However, as previously discussed, the RLH's PFI block is part of a campus typology which has scope to utilise alternative UAS to remain functional spatially.

The second architectural principle is spatial flexibility which needs urgent reform in PFI NHS hospitals. This status, argued by the NHS Confederation, is founded upon numerous new hospitals being reconfigured to accommodate for new medical technologies soon after completion (FHN, 2004:7). Of the four case studies examined, only UCLH and the RLH's urban block are PFI NHS hospitals but findings proved inconclusive in differentiating between technology's influence on PFI and non-PFI hospital space. POEs of PFI hospitals need to quantify the impact of change to inform any decision that determines their spatial flexibility. From my experience as a medical planner, creating specific spaces does not lend itself to be flexible. Therefore, the thesis can only determine the outcome for PFI NHS hospitals to be one of three scenarios where spatial flexibility will depend upon each PFI hospital's spatial status and future demands (see Table 8.7).

The third architectural principle is to revisit and learn from past mistakes. For example, spatial sustainability proved fatal after new technologies were introduced into late-20th century hospital buildings. This situation was weakened further by the then current NHS medical planning model. For PFI hospitals, information concerning the NHS's dismal delivery of a mat-building was crucial knowledge. Nevertheless, lessons learnt from the irrevocable outcome of Harness, Best-Buy and Nucleus hospitals were not addressed sufficiently in early PFI hospitals:

> Many of the new hospitals have not met expectations for a step change in quality and innovation in design and clinical solutions (Diamond, 2006:1).

This flaw in PFI NHS hospital design is reinforced by the strict compliance with HBN documentations. All PFI hospital spaces were designed to HBN guidance which do not account for medical ETs. As a result, many PFI NHS hospitals have embedded the same post-1980s flawed design models that do not consider the biggest driving influence of hospital design failure; medical technologies' future. Hence, whether PFI NHS hospitals become reclining white elephants across the British landscape will depend on the robustness of each hospital's architectural and medical planning solutions.

Scenario 1 – Refurbishment: During the 20-year period prior the *1962 Hospital Plan* programme, the architectural solution for spatial change was refurbishment. This response has a striking resemblance to the future status of PFI NHS hospitals. The main architectural response to future spatial evolution is expected to be one of refurbishment due to binding contractual agreements that the NHS must adhere to. Adaptability is therefore key to the success of PFI NHS hospitals. However, thesis scenarios have shown that not all existing hospital space is flexible and adaptable.

Scenario 2 – New build: By the 1980s, most NHS acute hospitals needed rebuilding. The Nucleus rebuilding programme resolved a short-term necessity that failed deliberately to include a sustainable strategy. The outcome witnessed the costly reconstruction of most NHS hospitals within twenty years. This event is underpinned by a vitally important lesson; the dilution of hospital space sizes and architectural quality is not sustainable. Therefore, a 20-year building life-span will be experienced if PFI hospitals have been built similarly. In the event of this trend continuing, PFI NHS hospitals will need rebuilding within twenty years. This scenario will require a new hospital rebuilding programme to commence in 2020, otherwise, the NHS will be delivering healthcare in out-of-date facilities for 50% of PFI contracts. Concerns for either outcome are exaggerated by medical ET's anticipated spatial impact which will require significant changes over the coming decades.

Scenario 3 – No change: This outcome is based on a scenario where finance is completely unavailable. In this event, as per previous trends, PFI NHS hospitals will deteriorate to a post-WII state of decay if they are not flexible.

Table 8.7 Three scenarios for future PFI NHS hospitals.

(ii) The second medical planning area concerns four spatial trends that extrapolate the durability of future PFI hospital space to be jeopardised (see Table 8.8). The first spatial trend encompasses all thesis findings which point to a future of hospital space and medical planning change. The second spatial trend identifies the wrong medical planning strategy has been incorporated to cater for these changes. Meanwhile, the third spatial trend questions the durability of PFI hospitals in response to new financially driven healthcare policies (2013). This emerging trend is transferring services in non-PFI hospitals to PFI NHS hospitals where financial commitments are obligatory but hospital space is at a minimum. Therefore, it is foreseen that future PFI hospital space will become pressurised greatly from transferred services unaccounted for spatially in original PFI NHS hospital designs. The fourth spatial trend is driven by a defaulted approach to hospital design. Louis Sullivan's 'form follows function' principle is embodied spatially to the extreme in PFI hospitals. For example, hospitals are derived from clinical briefs but PFI hospitals are designed as fractional units of specific functional space. This characteristic underpins this thesis' perspective that PFI NHS hospitals are contradictory in fundamental nature. An approach to spatial specifics is inappropriate as hospital space is forever evolving. As architect Bill Rostenberg argues:

> A tendency to pack too much functional space into a small, compact area usually will decrease operational efficiency and limit flexibility (Rostenburg, 2006:178-9).

Architect Susan Francis' belief further supports the argument that hospitals should not be designed as bespoke solutions, as models of care change substantially every five-to-ten years (Gates, 2005:7). Hence, the thesis considers PFI NHS hospitals will not be durable if a strict approach to spatial specifics was adhered to in original medical planning schemes.

Overall, the possibility of longevity seems weighted against PFI NHS hospitals. This perspective is supported by PFI hospitals' inflexible architectural solutions and lack of expansion space. To conclude, a bleak vision for spatial flexibility in PFI NHS hospitals is forecast by this thesis particularly for many urban block acute hospital buildings whose designs ignored the spatial failures of precedent late-20th century NHS hospitals.

Spatial trend	Anticipated concerns from spatial trends
(i) New medical planning arrangements driven by medical ETs	This study's trends and spatial implications identify major problems for PFI hospitals when evolving departments cannot be catered for spatially.
(ii) Wrong future spatial strategy for evolving technologies	Additional area to certain briefed rooms, such as, large high-tech rooms, was identified as insufficient in section 7.3.2. For example: (i) one PFI spatial strategy is a shelled-out OT room (55sqm). This is incorrect as new spaces in OTs will need distributing evenly; (ii) difficulties in replanning-existing columns disallow for new column free spaces.
(iii) Transfer of services to PFI hospitals	Closures at other hospitals are transfering services to PFI hospitals for financial reasons. Expensive PFI rented space will become pressurised.
(iv) Incorrect approach to design	By designing hospital space to HBN minimum standards, spatial flexibility is limited functionally.

Table 8.8 Four spatial trends envisioned to jeopardise PFI hospital space.

8.6 Chapter conclusion

This chapter has visualised broad trends for anticipated medical ETs in future urban acute hospitals. Spatial and medical planning visions for the year 2025 were delivered through three clinical UAT scenarios. This chapter's attempts to visualise an alternative future show medical ETs enhancing medical processes that will impact spatially on hospital environments in novel and different ways. Medical ETs are still in primitive forms but a future where technology does not impose on architecture is encouraged and has been shown to have potential. This finding reveals that spatial implications will allow for a shift in existing departmental boundaries. This revolution will demand a new medical planning model, that is composed of spatial parameters that are driven by medical ETs and new medical practices identified throughout the thesis.

The study emphasises the importance of alternative medical planning solutions, particularly those that implement future spatial flexibility at the 1:1000 scale. From findings, the durability of PFI NHS hospitals was determined as questionable. This decision was based on an assessment of spatial trends necessary for success that are underpinned by principles of spatial availability and adaptability. On this basis, the chapter closes with a final conclusion; flexible design solutions are obligatory for the success of future urban acute NHS hospitals.

Chapter 9: Conclusion

"We should all be concerned about the future because we have to spend the rest of our lives there"

Charles Kettering

9.0 Introduction

Chapter 9 summarises the thesis argument and objectives set out in Chapter 1 and assesses the degree to which each goal was achieved and the contribution made to the knowledge of medical planning. Thereafter, recommendations are put forward to guide medical planners with designing future urban acute NHS hospitals. The chapter closes with suggestions for further research to develop the area of medical planning.

9.1 Achievement of research objectives

Charles Kettering's perspective that *we should all be concerned about the future* is justified by the inevitability that *we have to spend the rest of our lives there*. As a medical planner, the central aim of the thesis was to offer an alternative vision for future NHS urban acute hospital space.

Part I of the thesis identified the purpose and need for this specific study. This directed the thesis research argument, aims and objectives in Chapter 1. Theoretical and contextual backgrounds were set out for investigation in Chapter 2 while Chapter 3 outlined the self-created single future prospective methodology adopted to achieve all four thesis objectives. Part II explored and confirmed technology's inter-related relationship with hospital space. Thesis findings were incorporated into Chapter 7's investigation of medical ETs which extrapolated a set of trends for future medical practice. All findings were collated to form Chapter 8's scenarios which underpinned the assessment of whether flexible design solutions are necessary in NHS hospitals. Four objectives directed data collection and analysis. The success in achieving each objective is assessed next.

The first objective was; to confirm the assumed relationship between hospital space and technology. Investigations of post-1800 medical planning and equipment events confirm that there is indeed a link between technological innovation and hospital space. This is based on thesis findings that reveal hospital spatial revolutions occurred simultaneously or immediately after advances in medical technologies took pace. For example, many new hospital spaces and departments appeared soon after the inventions of electrical medical equipment were introduced into hospital practice.

The second objective was: to investigate technology's influence as a driver of hospital medical planning. This objective was met by quantitatively assessing post-1800 British hospital space. Case study results revealed that high-tech hospital space increased dramatically between 1950-2012 but a defined ratio for spatial evolution was inconclusive. This outcome, however, does not diminish the role that medical technologies' have played in vastly changing the nature of late-20th century hospital space. For example, the formation of the D&T component and new hospital typologies, such as, the 'matchbox-on-a-muffin' model, are testament to the impact of technological innovation on medical planning. Hence, as a core factor in reconfiguring hospital space, medical technology was determined as a dominant driver of hospital medical planning.

The third objective was: to investigate the implications of medical ETs for future UAT treatments and their associated spaces. Broad medical trends were identified for three medical ETs of biotechnology, robotics and cyborgization. The implications of each technology revealed an alternative future for many existing UAT medical practices. Changes to many existing spatial requirements will be necessary for delivering future medical treatments. Scenarios revealed that future healthcare environments will differ significantly from existing NHS hospitals reinforcing the hypothesis that medical ETs will have a radical impact on the configuration of future urban acute hospital space.

The fourth objective was: to assess the necessity for flexible hospital design solutions. This objective was met by examining existing and alternative futures for PFI NHS hospitals with respect to medical ETs. Investigations indicate that fundamental changes are forecast for the spatial and medical planning of future urban acute hospitals with flexibility identified as essential for future-proofing PFI hospital space against future technology changes. Therefore, the current study firmly supports the necessity for flexible hospital design solutions.

9.2 Contributions of research

By investigating the area of medical technology and hospital space, this empirical research has made several contributions to developing the theoretical area of medical planning.

- The study's main theoretical contribution has been confirming medical technology's relationship with hospital space which underpins the hypothesis that medical ETs will radically impact on future urban acute hospital space. Findings provided critical knowledge concerning the spatial impact of technological innovation. Specifically, that a consistent trend in the reduction of medical equipment size exists as they evolve.
- The study uncovered clear evidence that technological innovation is indeed a dominant driver of the configuration of hospital space. It generated: a record and analysis of revolutionary medical planning events (400BC-2012); mapped the evolution of medical technology developments in hospitals (post-1800); performed a quantitative analysis of high-tech space for London's hospitals

(1840-2012); provided an understanding of the current state of NHS hospital space with regards to high-tech space; identified current hospital design drivers and anticipated trends that are driving spatial change.

- The research examined three medical ETs which indicate future medical equipment sizes to be either smaller than or equal to existing medical technologies. This finding contributes to knowledge; current medical planning strategies that ‘super-size’ rooms is incorrect for responding to future medical technology change.
- The research has produced a body of empirical evidence that identified trends and outcomes for future UAT practices and medical technologies. Findings informed the creation of alternative medical planning solutions which contribute theoretically to ‘outside-the-box’ concepts for designing future hospital space.
- The research indicated that flexible design solutions are necessary for future-proofing PFI NHS hospital space. This finding contributes to confirming the concern that the durability of PFI NHS hospitals is questionable.

9.3 Practical recommendations for future medical planning research

A series of practical recommendations are listed for future medical planning research.

- The study recommends that a central database is created explicitly for NHS hospital design. The central archive should be an accessible electronic database open to all and contain: historic hospital plans; original and updated PFI hospital drawings; relevant data regarding NHS hospitals, such as, lists of medical equipment and 1:50 drawings.
- The role of hospital archivists’ should be enhanced in preserving vital hospital design information. Archivists can be justified as data informants for the proposed new central NHS database.

- It is recommended that a POE programme is established to measure and monitor all PFI NHS hospital space. For example, research upon the ongoing spatial impact of emerging robotics in surgery. Benefits of a POE programme will create cost-saving strategies that encourage the long-term sustainability of NHS hospital estates.
- The implications of medical ETs and future practices need to be more widely disseminated among medical planners. More academic research on these subjects needs to be done and published to fill the gap in knowledge.
- Investment is key to all recommendations but shortfalls in this area are hindering the creation of new medical planning models that cater for medical ETs. However, the cost benefits of conducting HDR at present, specifically a detailed study of all Nucleus hospitals, outweigh the cost of having to rebuild the nations' NHS hospitals in the not so distant future.
- Flexible architectural solutions are key to all future hospital designs. Research dedicated to creating new construction methods, that embed ETs, needs to be developed and disseminated amongst architects.
- The challenge of uncertainty for medical planners can be explored by engaging in creative theories for inconsistency. Visions can be supported by past and anticipated trends provided within this thesis. Additionally, medical planners can draw from alternative medical planning approaches included within thesis scenarios that are underpinned with research into medical ETs.

9.4 Suggestions for further research

The following are suggestions for further research upon medical ETs and its implications upon future hospital space.

- The study explored three medical ETs but future studies that focus on individual technologies would provide a comparison between findings and results presented in this general study. For example, a focused study upon nanomedicine and its use within emergency care would contribute to the gap in medical planning knowledge and strengthens findings that emerged from this study’s investigation.
- Changes to hospital space are anticipated to respond to the growing mobility of medical ETs. Therefore, it is important to continue research, particularly at the 1:50 design scale, to develop spatial principles that respond to future technologies.
- The current study measured central London NHS acute hospitals only. Future empirical studies should explore alternative combinations of parameters, such as, types of hospital typology and location. Findings would make for informative comparison against the parameters of this particular study to enhance the understanding of medical technologies’ impact on future hospital space.
- The study’s sample represents only 3.4% of NHS acute hospitals. Further investigations that encompass a larger sample size are recommended to quantitatively measure the differences between PFI and D&B high-tech space as findings proved inconclusive within the context of this study.
- The thesis focuses on NHS public hospitals explicitly. A study of private hospitals would offer an alternative perspective, as the organisation of healthcare is driven by different parameters. As stated previously, this is a main reason why American research cannot be implemented directly in NHS hospitals. Research upon this variable is very much needed to provide useful data to benefit the design and operation of NHS hospitals.

The thesis demonstrates hospital space and medical technologies are linked strongly. Further to this, the impact of medical ETs on future urban acute hospital space is indicated to be radical. Important medical planning findings provide insight into future-proofing NHS hospitals. As a source of guidance for medical planners in designing future urban acute hospitals with respect to medical ETs, this study will assist in creating a foundation for *a new hospital architecture*.

Appendix A

1.1 Background to thesis

Clinical example: If an MRI machine breaks down

- Out-patient appointments are cancelled causing serious disruption to the organisation of patient waiting times
- Acute patients may need to be transferred to another hospital
- Use of alternative radiological machines creates delays and inaccurate diagnosis possibilities
- Death of patient due to delay in diagnosis and treatment

Non-clinical example: If any part of the IT network system goes down

- Patient records are inaccessible
- Out-patient appointments are cancelled
- Pharmacy deliveries are cancelled and pathological results are delayed
- Physicians and nurses cannot analyse scan results for diagnosis
- Information from the Imaging department is delayed or inaccessible
- Remote patients cannot be treated from home
- Patients dietary requirements may be wrongly diagnosed
- Security network may be penetrated
- ICU monitoring may be effected
- Death of patient due to time delay of information or treatment

Appendix A.1 Tabled examples: Failure of technology in hospitals.

1.2 Thesis argument

Based on a series of sub-questions, four research objectives were established to assist with proving the thesis argument:

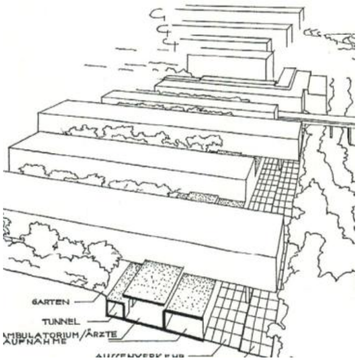
> Based on a defined relationship that exists between hospital space and technology, anticipated ET in future medical practice will radically affect future urban acute hospital space.

Thesis objectives	Sub-questions
1. To confirm the assumed relationship between hospital space and technology.	- What is the relationship between hospital space and technology?
2. To investigate technology's influence as a driver of hospital medical planning.	- Is technology a key driver of hospital space? - How does technology influence hospital space and medical planning?
3. To investigate the implications of ET for future UAT treatments and associated spaces.	- What medical ET are predicted? - What fundamental differences exist between existing and future medical technologies? - How will ET affect medical practice in hospitals? - Will the changes to medical practice impact on hospital space? - How will the incorporation of ET affect future hospital space? - What spatial and medical planning trends can be identified?
4. To assess the necessity for flexible hospital design solutions.	- Are current 'state-of-the-art' PFI NHS acute hospitals sufficiently future-proofed to cope with future technology changes that will sustain complete clinical and spatial functionality throughout their contracted 35-40 year life span? - Is flexibility required to respond to the future use of ET in future urban acute hospitals?

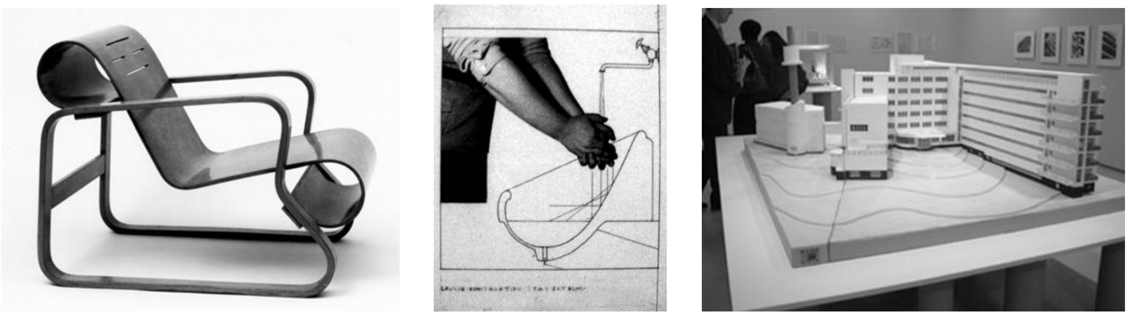
Appendix A.2 List of thesis objectives and sub-questions.

Appendix B

2.1.1 The Paimio Sanatorium, Alvar Aalto

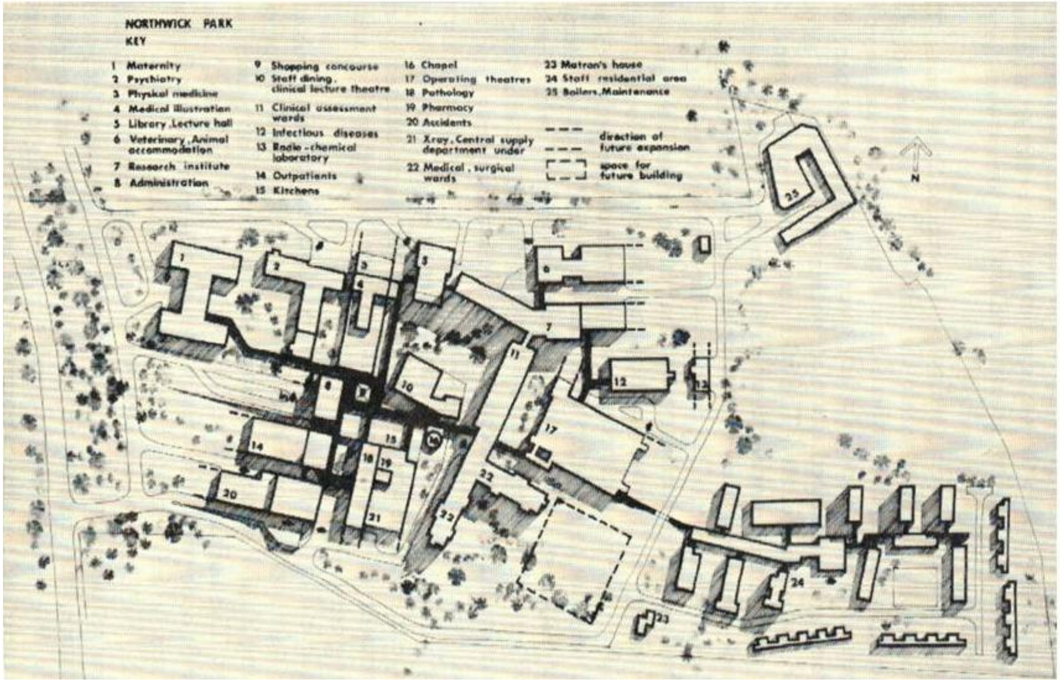


Appendix B.1 Zagreb central hospital competition plan, 1931 (Schildt, 1994:69).



Appendix B.2 From left to right: Aalto's Paimio chair (manufactured by Artek), Aalto's Splash-free sinks, model of The Paimio Sanatorium [Online]. Available at: http://www.designboom.com/history/aalto/paimio.html (Accessed: 12th July 2011).

2.1.2 Northwick Park Hospital, John Weeks

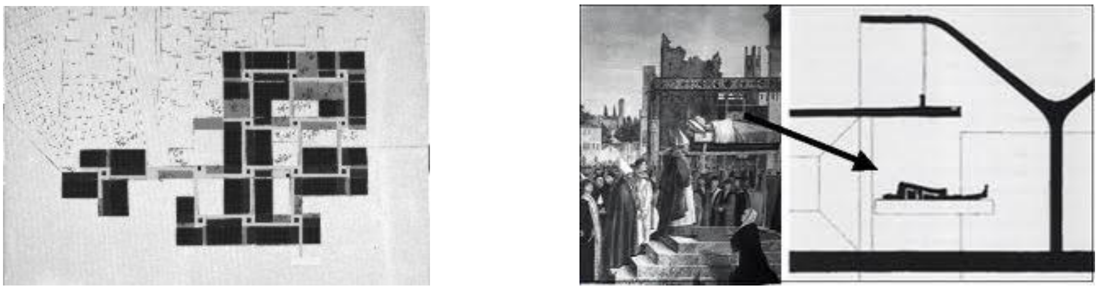


Appendix B.3 Masterplan of Northwick Park Hospital (Weeks, 1963-4:103).

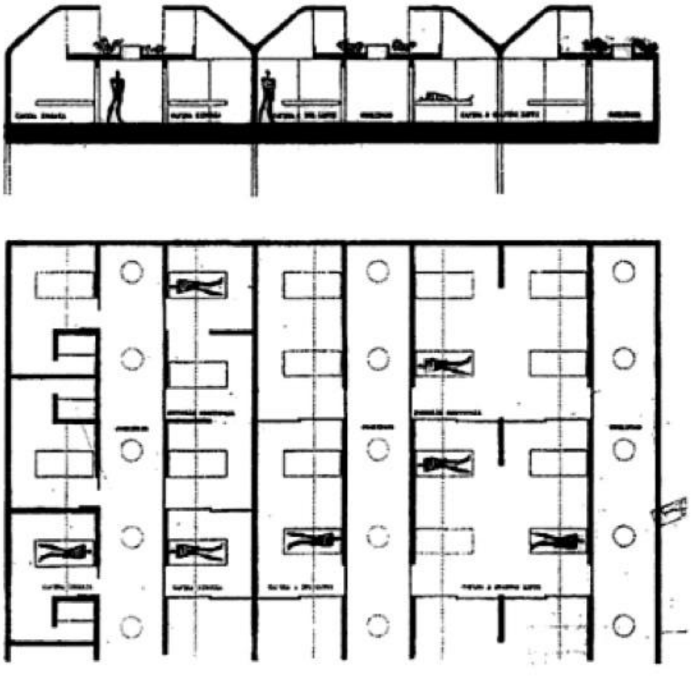
2.1.2 Northwick Park Hospital, John Weeks

Appendix B.4 Left to right: Model and front entrance perspective of Northwick Park Hospital (Weeks, 1966:338-9).

2.1.3. Ospedale Civile, Le Corbusier



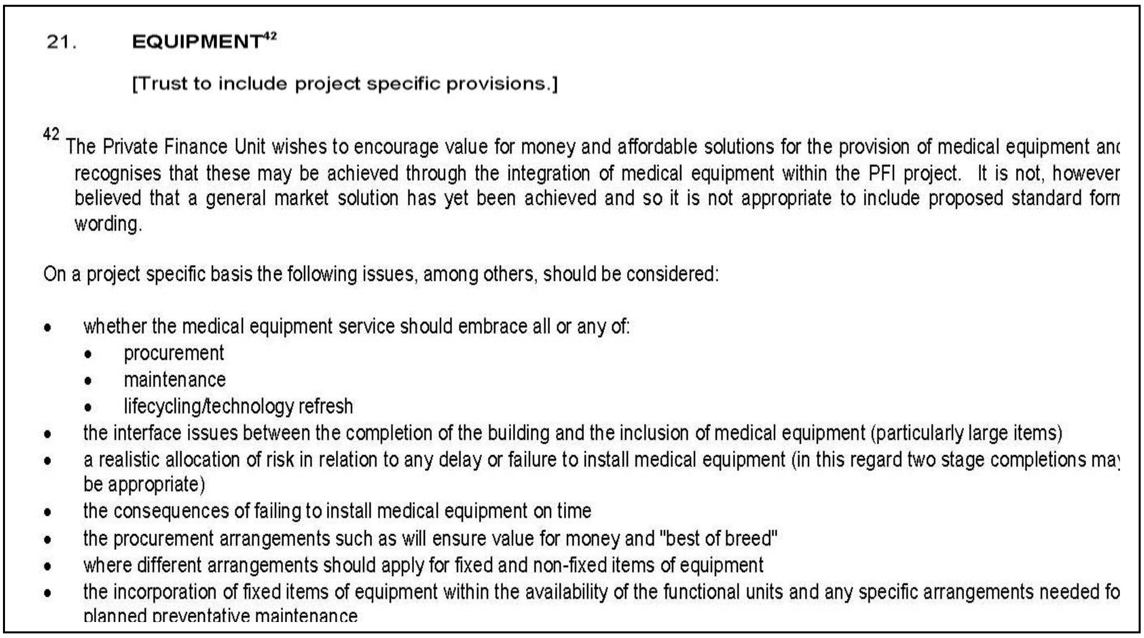
Appendix B.5 Masterplan and section (project 3, 1965) of Ospedale Civile (Sarkis, 2001).



2.5. Le Corbusier, City Hospital of Venice, section and plan

Appendix B.6 Plan of ward level and section through the Ospedale Civile. Third iteration of the project between 1964-6 (Sarkis, 2001:74).

2.2.4 Design process of PFI NHS acute hospitals



21. **EQUIPMENT**[42]

[Trust to include project specific provisions.]

[42] The Private Finance Unit wishes to encourage value for money and affordable solutions for the provision of medical equipment an recognises that these may be achieved through the integration of medical equipment within the PFI project. It is not, howeve believed that a general market solution has yet been achieved and so it is not appropriate to include proposed standard for wording.

On a project specific basis the following issues, among others, should be considered:

- whether the medical equipment service should embrace all or any of:
  - procurement
  - maintenance
  - lifecycling/technology refresh
- the interface issues between the completion of the building and the inclusion of medical equipment (particularly large items)
- a realistic allocation of risk in relation to any delay or failure to install medical equipment (in this regard two stage completions ma be appropriate)
- the consequences of failing to install medical equipment on time
- the procurement arrangements such as will ensure value for money and "best of breed"
- where different arrangements should apply for fixed and non-fixed items of equipment
- the incorporation of fixed items of equipment within the availability of the functional units and any specific arrangements needed fo planned preventative maintenance

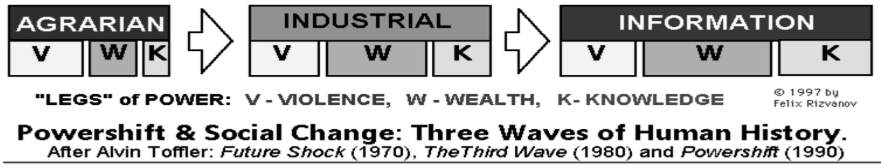
Appendix B.7 *Department of Health Standard Form Project Agreement Version 3* (DOH, 2005:27).

PITN, Documentation to be issued to the bidders by the Trust to include:

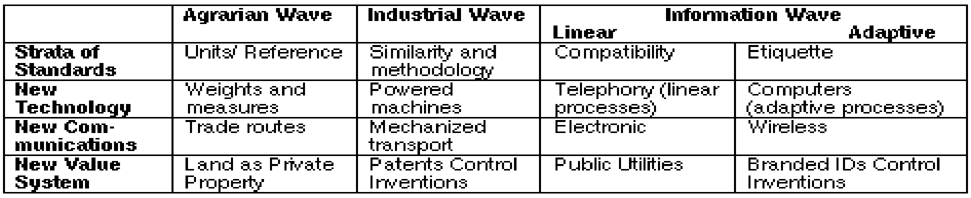
- BOQ
- Service Level Specifications
- Risk Transfer assumptions
- Output specs for big ticket items

Appendix B.8 PFI guidance for medical equipment (DOH, 2005:2).

2.3.1 Background to technology development



Appendix B.9 Toffler: Defining the three waves of change as events occurred (Rizvanov, 1997).



	Agrarian Wave	**Industrial Wave**	**Information Wave**	
			Linear	**Adaptive**
Strata of Standards	Units/ Reference	Similarity and methodology	Compatibility	Etiquette
New Technology	Weights and measures	Powered machines	Telephony (linear processes)	Computers (adaptive processes)
New Com-munications	Trade routes	Mechanized transport	Electronic	Wireless
New Value System	Land as Private Property	Patents Control Inventions	Public Utilities	Branded IDs Control Inventions

Appendix B.10 Toffler: Three ‘waves of change’ (Krechmer,1999: Table 1)[1].

---

[1] Presented at the First IEEE Conference on Standardization and Innovation in Information Technology (SIIT), September 16, 1999, Aachen, Germany. Technical Communications Standards: New Directions in

2.3.5 Robert A. Freitas, Jr.: Nanomedicine

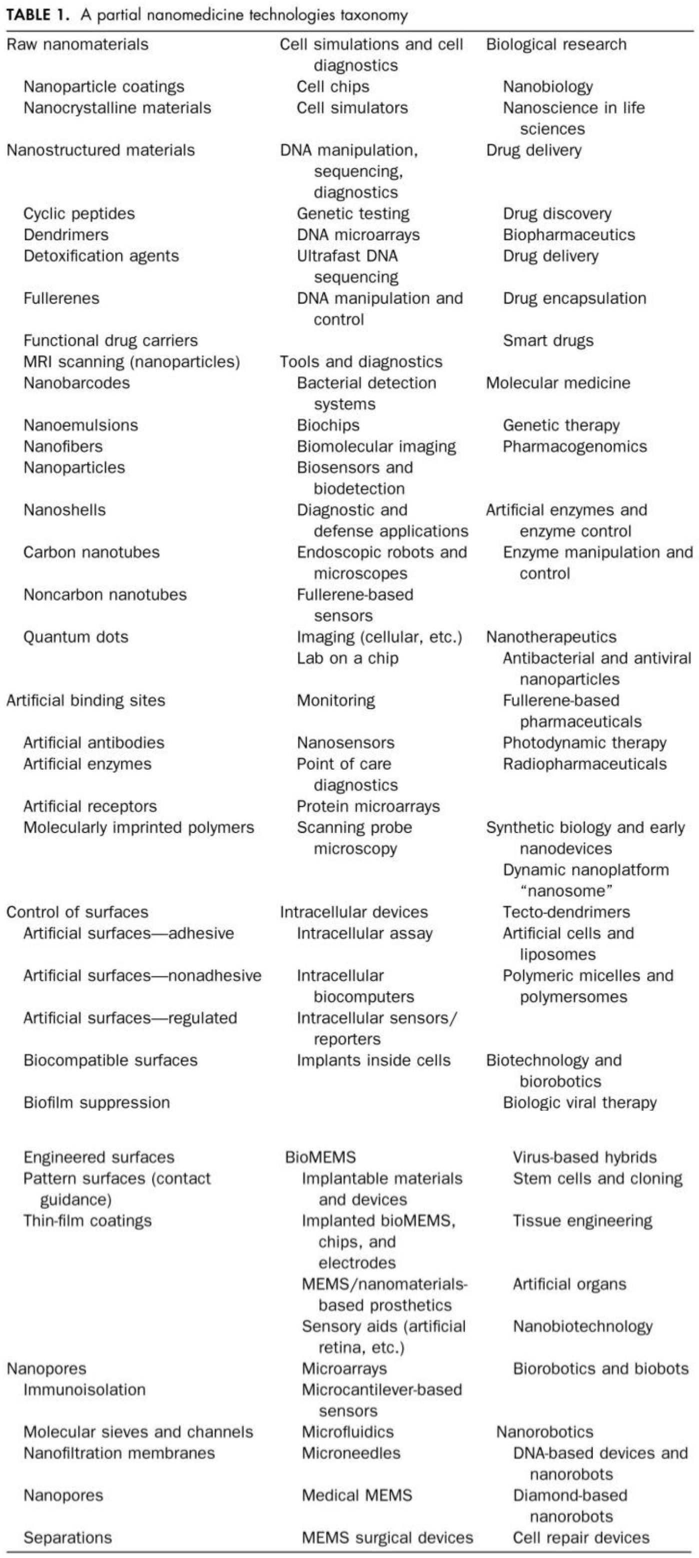


TABLE 1. A partial nanomedicine technologies taxonomy

- Raw nanomaterials
  - Nanoparticle coatings
  - Nanocrystalline materials
- Nanostructured materials
  - Cyclic peptides
  - Dendrimers
  - Detoxification agents
  - Fullerenes
  - Functional drug carriers
  - MRI scanning (nanoparticles)
  - Nanobarcodes
  - Nanoemulsions
  - Nanofibers
  - Nanoparticles
  - Nanoshells
  - Carbon nanotubes
  - Noncarbon nanotubes
  - Quantum dots
- Artificial binding sites
  - Artificial antibodies
  - Artificial enzymes
  - Artificial receptors
  - Molecularly imprinted polymers
- Control of surfaces
  - Artificial surfaces—adhesive
  - Artificial surfaces—nonadhesive
  - Artificial surfaces—regulated
  - Biocompatible surfaces
  - Biofilm suppression
  - Engineered surfaces
  - Pattern surfaces (contact guidance)
  - Thin-film coatings
- Nanopores
  - Immunoisolation
  - Molecular sieves and channels
  - Nanofiltration membranes
  - Nanopores
  - Separations
- Cell simulations and cell diagnostics
  - Cell chips
  - Cell simulators
- DNA manipulation, sequencing, diagnostics
  - Genetic testing
  - DNA microarrays
  - Ultrafast DNA sequencing
  - DNA manipulation and control
- Tools and diagnostics
  - Bacterial detection systems
  - Biochips
  - Biomolecular imaging
  - Biosensors and biodetection
  - Diagnostic and defense applications
  - Endoscopic robots and microscopes
  - Fullerene-based sensors
  - Imaging (cellular, etc.)
  - Lab on a chip
  - Monitoring
  - Nanosensors
  - Point of care diagnostics
  - Protein microarrays
  - Scanning probe microscopy
- Intracellular devices
  - Intracellular assay
  - Intracellular biocomputers
  - Intracellular sensors/reporters
  - Implants inside cells
- BioMEMS
  - Implantable materials and devices
  - Implanted bioMEMS, chips, and electrodes
  - MEMS/nanomaterials-based prosthetics
  - Sensory aids (artificial retina, etc.)
  - Microarrays
  - Microcantilever-based sensors
  - Microfluidics
  - Microneedles
  - Medical MEMS
  - MEMS surgical devices
- Biological research
  - Nanobiology
  - Nanoscience in life sciences
- Drug delivery
  - Drug discovery
  - Biopharmaceutics
  - Drug delivery
  - Drug encapsulation
  - Smart drugs
- Molecular medicine
  - Genetic therapy
  - Pharmacogenomics
- Artificial enzymes and enzyme control
  - Enzyme manipulation and control
- Nanotherapeutics
  - Antibacterial and antiviral nanoparticles
  - Fullerene-based pharmaceuticals
  - Photodynamic therapy
  - Radiopharmaceuticals
- Synthetic biology and early nanodevices
  - Dynamic nanoplatform “nanosome”
  - Tecto-dendrimers
  - Artificial cells and liposomes
  - Polymeric micelles and polymersomes
- Biotechnology and biorobotics
  - Biologic viral therapy
  - Virus-based hybrids
  - Stem cells and cloning
  - Tissue engineering
  - Artificial organs
  - Nanobiotechnology
  - Biorobotics and biobots
- Nanorobotics
  - DNA-based devices and nanorobots
  - Diamond-based nanorobots
  - Cell repair devices

Appendix B.11 Table 1: A Partial nanomedicine technologies taxonomy (Freitas Jr., 2005: 328-9).

Innovation by Ken Krechmer, Fellow, International Center for Standards Research University of Colorado at Boulder Communications Standards Review [Online]. Available at: http://www.csrstds.com/siit.html (Accessed: 30th July 2013).

Appendix C

3.1.1 Identifying research variables

(v) Technological specification Four ET omitted from reseach

(i) Light emissions/laser technology (LET): Based on photonic theories, this technology manipulates light for the transportation of information. With very strong structural and lighting characteristics, this technology has future possibilities for the architectural environment. Although the discovery of nanotubes has greatly evolved LET, as of yet, no practical applications have been discovered of relevance to this study.

(ii) Optical computing/Interactive motion technology: At UCL's London Centre for Nanotechnology[1], numerous applications are in progress using optical computing technology. The hope is to create a diagnostic formula that does not use radiography for the treatment of breast lesions. The Weizmann Institute in Israel is making similar progress with this technology by developing medical equipment for the diagnoses of breast tumours. Both ET are extremely promising but only address a small sector of medical care rather than the broad field expectations which this study wishes to address.

(iii) Wave technology: Involving the use of light, heat and radio waves, wave technology is breaking new ground through the exploration of different parts of the light spectrum. For example, research at the Beth Israel Deaconess Medical Centre is focusing on disrupting cancer cells by bioelectric pulses and open spine surgery (Combs, 2006:1310). Again this technology is limited to a specific medical area.

---

[1] Working with Quantua-Image, Photonics, Mytec Technologies and Lockheed companies.

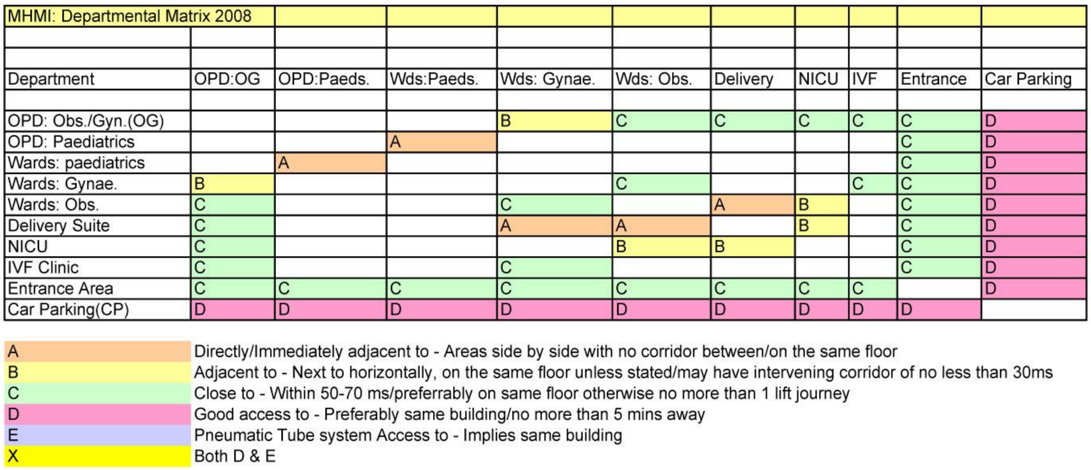
(iv) Quantum Dots (QDs): In 1981, Feynman suggested a theory for quantum computers which he anticipated information storage could be located at the atomic level. Incorporating quantum theories, engineers are currently focusing on the development of QDs whose main goal is to store infinite digital information at extreme speeds. This novel technology can potentially replace Moore’s Law for computer technology where huge memory spaces at faster rates will significantly develop medical technologies into the next generation of powerful medical equipment. From a medical perspective, ‘the use of quantum dots for biological applications is one of the fastest moving fields of nanotechnology today’ as QDs are used for fluorescence in MRI and CT contrasting agents. As Freitas explains:

> Quantum dots are being investigated as chemical sensors, for cancer cell detection, gene expression studies, gene mapping and DNA microarray analysis,...medical diagnostics and drug screening,...vascular imaging, and many other applications (Freitas Jr., 2005:3).

At present, QDs production status is limited but its potential is hugely anticipated for all existing and future technologies.

Appendix C.1 Technological specification of four ET identified but omitted from research.

3.1.2 Concept mapping: Defining hospital design influences



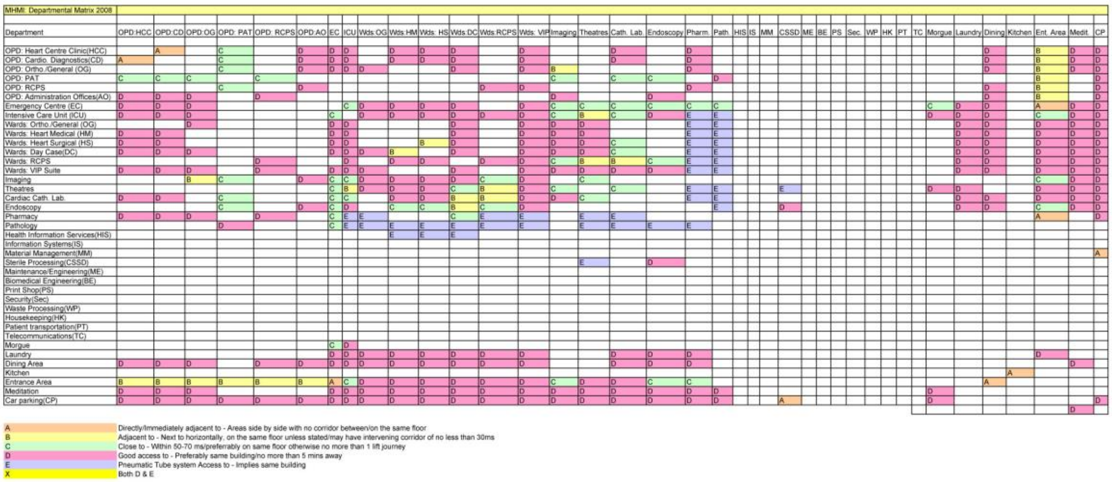
MHMI: Departmental Matrix 2008

Department	OPD:OG	OPD:Paeds.	Wds:Paeds.	Wds: Gynae.	Wds: Obs.	Delivery	NICU	IVF	Entrance	Car Parking
OPD: Obs./Gyn.(OG)				B	C	C	C	C	C	D
OPD: Paediatrics			A						C	D
Wards: paediatrics		A							C	D
Wards: Gynae.	B				C			C	C	D
Wards: Obs.	C			C		A	B		C	D
Delivery Suite	C			A	A		B		C	D
NICU	C				B	B			C	D
IVF Clinic	C			C					C	D
Entrance Area	C	C	C	C	C	C	C	C		D
Car Parking(CP)	D	D	D	D	D	D	D	D	D	

A	Directly/Immediately adjacent to - Areas side by side with no corridor between/on the same floor
B	Adjacent to - Next to horizontally, on the same floor unless stated/may have intervening corridor of no less than 30ms
C	Close to - Within 50-70 ms/preferrably on same floor otherwise no more than 1 lift journey
D	Good access to - Preferably same building/no more than 5 mins away
E	Pneumatic Tube system Access to - Implies same building
X	Both D & E

Appendix C.2 Typical clinical adjacency matrix for designing an acute hospital: MHMI Departmental Matrix (Burke, 2008).

3.1.2 Concept mapping: Defining hospital design influences

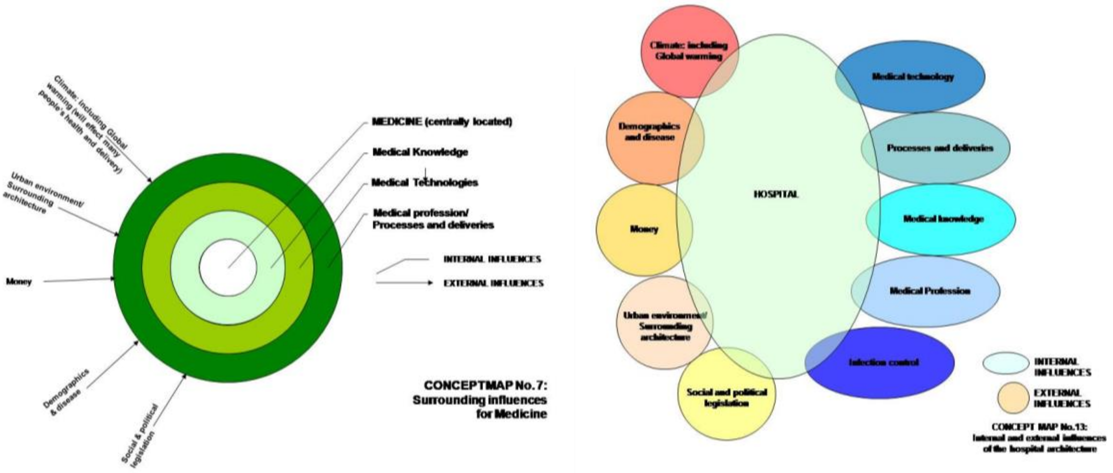


MHMI: Departmental Matrix 2008

Department	OPD:HCC	OPD:CD	OPD:OG	OPD: PAT	OPD: RCPS	OPD:AO	EC	ICU	Wds:OG	Wds:HM	Wds: HS	Wds:DC	Wds:RCPS	Wds: VIP	Imaging	Theatres	Cath. Lab.	Endoscopy	Pharm.	Path.	HIS	IS	MM	CSSD	ME	BE	PS	Sec.	WP	HK	PT	TC	Morgue	Laundry	Dining	Kitchen	Ent. Area	Medit.	CP
OPD: Heart Centre Clinic(HCC)		A		C		D	D	D		D	D	D		D			D		D																D		B	D	D
OPD: Cardio. Diagnostics(CD)	A			C		D	D	D		D	D	D		D			D		D																D		B	D	D
OPD: Ortho./General (OG)				C		D	D	D	D			D		D	B				D																D		B	D	D
OPD: PAT	C	C	C		C										C		C	C		D																	B		D
OPD: RCPS				C		D							D	D					D																D		B		D
OPD: Administration Offices(AO)	D	D	D		D										D			D																	D		B		D
Emergency Centre (EC)	D	D	D					C	D	D	D	D		D	C	C	C	C	C	C													C	D	D		A	D	D
Intensive Care Unit (ICU)	D	D	D				C		D	D	D	D	D	D	C	B	C	D	E	E													D	D	D		C	D	D
Wards: Ortho./General (OG)			D				D	D				D		D	D	D			E	E														D	D		D	D	D
Wards: Heart Medical (HM)	D	D					D	D				D		D	D	D			E	E														D	D		D	D	D
Wards: Heart Surgical (HS)	D	D					D	D			B	D		D	D	D	C		E	E														D	D		D	D	D
Wards: Day Case(DC)	D	D	D				D	D	D	B		D		D	D	D	C		E	E														D	D		D	D	D
Wards: RCPS					D			D		D	D		D	D	C	B	B	C	E	E														D	D		D	D	D
Wards: VIP Suite	D	D	D		D		D	D	D			D		D	D	D	D	D	E	E														D	D		D	D	D
Imaging			B	C		D	C	C	D	D	D	D	C	D		C																					C	D	D
Theatres							C	B	D	D	D	C	B	D	C		C		E	E				E									D	D			D	D	D
Cardiac Cath. Lab.	D	D		C			C	C		D	D	B	B	D	D	C			E	E														D	D		D	D	D
Endoscopy				C		D	C	D		C	C	B	C	D						E				D										D	D		C	D	D
Pharmacy	D	D	D		D		C	E	E			C	E	E		E	E																				A		D
Pathology				D			C	E	E	E	E	E	E	E		E	E	E	E																				
Health Information Services(HIS)										E	E	E																											
Information Systems(IS)																																							
Material Management(MM)																																							A
Sterile Processing(CSSD)																E		D																					
Maintenance/Engineering(ME)																																							
Biomedical Engineering(BE)																																							
Print Shop(PS)																																							
Security(Sec)																																							
Waste Processing(WP)																																							
Housekeeping(HK)																																							
Patient transportation(PT)																																							
Telecommunications(TC)																																							
Morgue							C	D																															
Laundry							D	D	D	D	D	D	D	D			D	D	D																		D		
Dining Area	D	D	D		D	D	D	D	D	D	D	D	D	D			D	D	D																			D	
Kitchen																																				A			
Entrance Area	B	B	B	B	B	B	A	C	D	D	D	D	D	D	C	D	D	C	C																A				
Meditation	D	D	D				D	D	D	D	D	D	D	D	D	D	D	D	D	D													D						
Car parking(CP)	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D				A									D						D
																																						D	

A	Directly/Immediately adjacent to - Areas side by side with no corridor between/on the same floor
B	Adjacent to - Next to horizontally, on the same floor unless stated/may have intervening corridor of no less than 30ms
C	Close to - Within 50-70 ms/preferrably on same floor otherwise no more than 1 lift journey
D	Good access to - Preferably same building/no more than 5 mins away
E	Pneumatic Tube system Access to - Implies same building
X	Both D & E

Appendix C.3 Typical clinical adjacency matrix for designing an acute hospital (Burke, 2008).

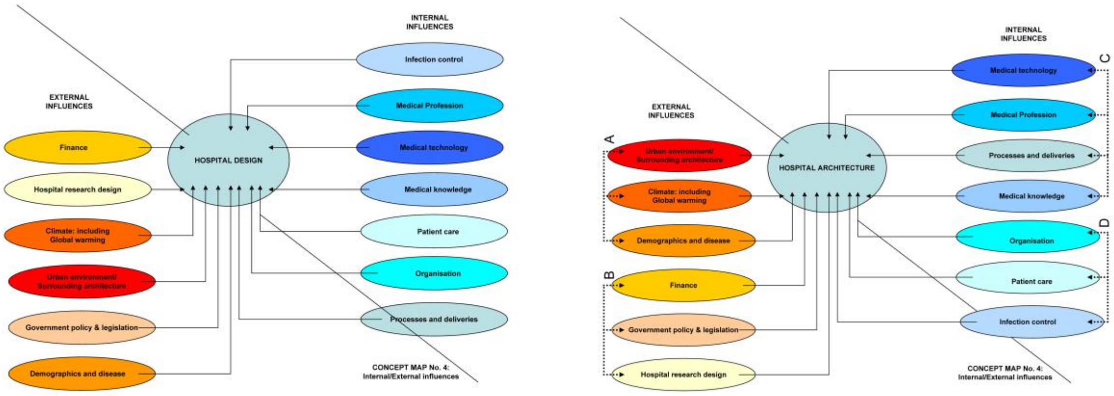


Appendix C.4 Left: Exemplar Concept map No. 7 investigates the influences of medicine on hospital design. **Right:** Exemplar Concept Map No.10: To establish the influences of hospital design.

List of influences		
1. Demographics	6. Medical professions	11. Finance
2. Epidemiology	7. Processes of care	12. Legislation
3. Medical knowledge	8. Government policy	13. Urban environment/climate
4. Delivery of care	9. Infection control	14. Medical technologies
5. Model of care	10. Hospital organisation	15. Hospital design research

Appendix C.5 Results from concept mapping: List of fifteen influences**.**

3.1.2 Concept mapping: Defining hospital design influences



Appendix C.6 Left: Division of hospital design factors into external and internal influences. **Right:** Influences of hospital design divided into groups.

List of Relationships	
Influence	**Influential upon**
Technology:	⮜ Medical knowledge ➢ Delivery of care ➢ Processes of care ➢ Model of care ➢ Medical professions ⮜ Finance
Knowledge:	➢ Delivery of care ⮜ Epidemiology
Delivery of care:	➢ Processes of care ➢ Medical professions
Model of care:	➢ Medical professions ➢ Hospital organisation
Processes of care:	➢ Medical professions
Finance:	⮜ Legislation ⮜ Government policy
Legislation:	⮜ Government policy
Hospital organisation:	⮜ Government policy
Delivery of care:	⮜ Infection control
Epidemiology:	⮜ Urban environment & climate ⮜ Demographics
Demographics:	⮜ Urban environment & climate
Hospital design research:	➢ Delivery of care ➢ Model of care ➢ Processes of care

Appendix C.7 Results from concept mapping: Twenty four relationships established.

3.1.2 Concept mapping: Defining hospital design influences

Grouping	Factors	No. of identified relationships
Medical	➢ Medical technologies ➢ Medical knowledge ➢ Delivery of care ➢ Model of care ➢ Medical profession ➢ Hospital design research ➢ Processes of care	➢ 6 ➢ 3 ➢ 5 ➢ 4 ➢ 4 ➢ 3 ➢ 4
Organisational	➢ Hospital organisation ➢ Government policy ➢ Finance ➢ Legislation	➢ 2 ➢ 3 ➢ 3 ➢ 2
Environmental	➢ Demographics ➢ Infection control ➢ Urban environment & climate ➢ Epidemiology	➢ 1 ➢ 1 ➢ 1 ➢ 4
Total	➢ **15 design factors**	➢ **24 relationships**

Appendix C.8 Table of external and internal influences highlighting which factors are dominant influences in the design of urban acute hospital.

Group	External	Group	Internal
A	1. Demographics and epidemiology 2. Urban environment/climate	**C**	1. Medical knowledge & practice 2. Changing roles 3. Delivery and processes 4. Medical technologies
B	1. Government legislation/policy 2. Finance 3. Research in design	**D**	1. Patient care and requirements 2. Organisation 3. Infection control

Appendix C.9 Chart of external and internal influences on hospital design

3.3 Research framework

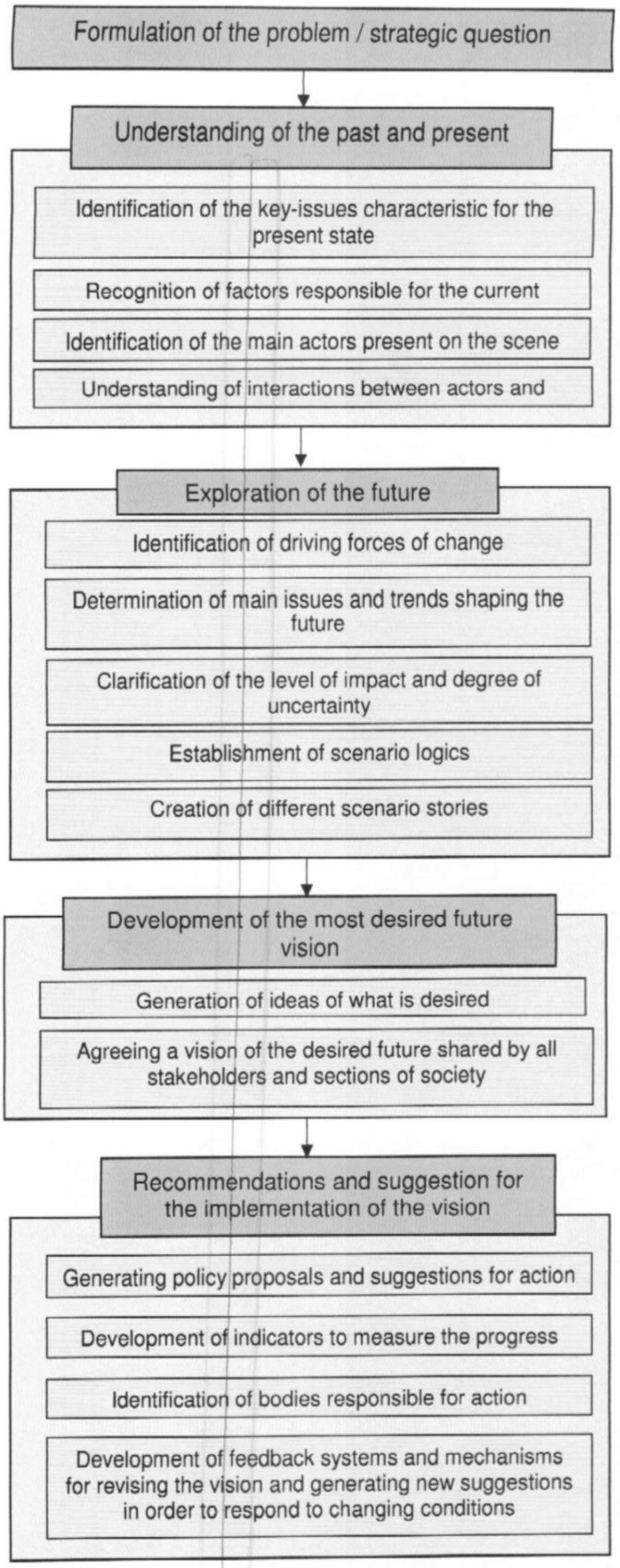


Fig. 1. The Prospective process

Appendix C.10 John Ratcliffe: *The Prospective process* (Krawczyk & Ratcliffe, 2005:8).

3.5 Quantitative framework: Case study sample criterion

High-tech Building Components: Clinical & non-clinical areas	
Department	**Functionality**
1. A&E	Resuscitation, trauma, observation and assessment
2. Imaging	Diagnostics through the use of high-spec technology: Multi-slice CT scanner, PET/CT scanner, Fluoroscopy, General Xray, MRI
3. Theatres	Specialist and interventional theatres, anaesthetic rooms, etc.
4. Endoscopy	Diagnostics and treatment via varied endoscopes
5. Pharmacy	High-tech laboratory areas with higher M&E requirements
6. Pathology	High-tech laboratory areas with higher M&E requirements
7. Nuclear Medicine	Radiography for cancer treatment
8. CSSD[2]	Sterile services for all equipment
9. Mortuary	Post-mortems and body storage
10. Kitchen	Food provision
11. Laundry	Hospital hygiene
12. FM	Facility Management has many supporting departments

Appendix C.11 High-tech hospital components.

Low-tech Building Components: Clinical & non-clinical areas	
Department	**Activity**
1. OPD	Consultation, examination and minor procedural areas
2. Wards	Located separate from clinical areas due to different functional requirements, environmental conditions and constructional costs
3. ICU/HDU/CCU	Intensive nursing care units
4. Offices	Administration accommodation located throughout hospitals, functions as a non-clinical support service. Includes medical records
5. Teaching	Facilities for teaching such as seminar rooms, classrooms, or simulator rooms.

Appendix C.12 Low-tech hospital components.

3.6 Data Collection

Case study No.1: The Royal London Hospital		
	Dates	**Time spent**
Duration for locating drawings	Jan. 2009 – May 2010	17 months
Measuring/logging drawings	May 2009- April 2010	12 months
Calculation of measured drawings	April 2010	1 month
Tabling measured data	June 2010 – July 2010	2 months

Appendix C.13 Journal of collected data for Case Study No.1: The Royal London Hospital.

---

[2] CSSD - Central sterile services department

3.6 Data Collection

Case study No.1: The Royal London Hospital						
	Plans	**No. of floors**	**Measured**	**Hard copy**	**Electronic copy**	**Organisation**
1832	Yes	5	By hand	Yes	No	Voluntary
1886	Yes	5	By hand	Yes	No	Voluntary
1900	Yes	6	By hand	Yes	No	Voluntary
1950	Yes	6	By hand	Yes	No	NHS
2000	Yes	8	By hand	Yes	No	NHS
2012	Varied: Plans & SOA	20	By hand, except PP*	Yes, except PP*	Yes	NHS/PFI

* PP Relates to the new Pharmacy and Pathology building. Area calculations were taken directly from SOA spreadsheets.

Appendix C.14 Tabled format of process for measuring plans dating 1832-2010.

Case study No.2: St. Thomas' Hospital		
	Dates	**Time spent**
Duration for locating drawings	Feb. 2009 – Aug. 2009	2 weeks at St. Thomas's offices
Measuring/logging drawings	Sept. 2009 – Dec. 2009	4 months
Calculation of measured drawings	March 2010	1 month
Tabling measured data	May 2010 – July 2010	3 months

Appendix C.15 Journal of collected data for Case Study No.2: St. Thomas' Hospital

Case study No.2: St. Thomas' Hospital						
	Plans	**No. of floors**	**Measured**	**Hard copy**	**Electronic copy**	**Organisation**
1880	Varied	6	By hand	Yes	Yes	Royal
1900	Varied	6	By hand	Yes	Yes	Royal
1950	Varied	6	By hand	Yes	Yes	NHS
2010	Varied	Max. 15	By Excel spread sheet	Majority of plans available	Yes	NHS

Appendix C.16 Tabled format of process for measuring plans dating 1880-2010.

3.6 Data Collection

Case study No.3: The Chelsea and Westminster Hospital		
	Dates	**Time spent**
Duration for locating drawings	Jan. 2009 – March 2009	Full set of electronic drawings received by email.
Measuring/logging drawings	June 2009-July 2009	2 months
Calculation of measured drawings	April 2010	1 month
Tabling measured data	June 2010	1 month

Appendix C.17 Journal of collected data for Case Study No.3: The Chelsea and Westminster Hospital.

Case study No.3: The Chelsea and Westminster Hospital						
	Plans	**No. of floors**	**Measured**	**Hard copy**	**Electronic copy**	**Organisation**
Prior 1990	NA*	NA*	NA*	NA*	NA*	Voluntary/ NHS on different site
2012	Yes	8	By hand	Yes	Yes	PFI

Appendix C.18 Tabled format of process for measuring plans dating 1832-2010.

Case study No.4: UCLH		
	Dates	**Time spent**
Duration for locating drawings	May 2009- Aug. 2011(?)	Drawings received electronically with updated spreadsheets
Measuring/logging drawings	August 2011	1 month
Calculation of measured drawings	September 2011	1 month
Tabling measured data	Oct 2011	1 month

Appendix C.19 Journal of collected data for Case Study No.4: UCLH

Case study No.4: UCLH						
	Plans	**No. of floors**	**Measured**	**Hard copy**	**Electronic copy**	**Organisation**
1832 - 2006	N/A	N/A	N/A	N/A	N/A	Voluntary/NHS
2006	Varied	20	By excel spreadsheet	No	Yes	PFI

Appendix C.20 Tabled format of process for measuring plans dating 1832-2010.

3.7 Data analysis: Case studies

List of Terminologies

1. Gross Departmental Area (GDA): All departmental areas are measured to the centre line of a departmental boundary wall.

2. Gross Communications Area (GCA): is the abbreviation for all communication or circulation areas between departments, commonly known as ‘Comms.’. This includes lift cores and stairways unless specifically designated to a particular department. The calculation of ‘Comms.’ areas are to the centre line of the boundary walls or flush to the division line of an open space.

3. Gross Plant Area (GPA): Plant includes all plant areas throughout the building. This includes all risers and is also measured to the central line of the wall.

4. Gross Facility Management Area (GFMA): Designated Facility Management (FM) areas are only present in PFI hospital plans. They relate to the non-clinical areas designated to a consortium’s FM areas. As the ownership of estates has changed under PFI, FM spaces are not new types or additional spaces. They are calculated separately for financial reasons only. The GFMA refers to the hospital building’s total FM areas.

5. Gross Building Area (GBA): GBA is the total area of the building which is the combined calculations for GDA + GCA + GPA + GFMA.

Appendix C.21 List of terminologies and descriptions.

3.8 Data Analysis: Scenario creation

Department List	Room List	ADB code	Procedure Type	HBN Number
A&E	1. Resuscitation room	X0231	Diagnostic & Treatment	HBN 22 (2005)
	2. Assessment room	C0302		
	3. Multi-functional room	X0242		
Imaging	4. General X-ray	E0124	Diagnostic	HBN 06V2 (April 2003)
	5. Ultrasound	E0119		
	6. CT suite	E0601		
	7. MRI suite	E0801		
	8. MRI Control room	E0804		
Theatres	9. Operating Theatre	N0106	Diagnostic & Treatment	HBN 26 Vol. 1 (2004)
	10. Anaesthetic room	N0316		
	11. Scrub	N0216		
	12. Preparation	T0526		
	13. Dirty Utility	Y0420		
Pathology	14. Automated Laboratory	L0201	Diagnostic	HBN 15 2nd ed. (2005)
	15. Laboratory: Microbiology	L0301		
	16. Laboratory: Haematology	L0413		
	17. Laboratory: Histopathology	L0814		
	18. Laboratory: Cytopathology	L0904		
Pharmacy	19. Preparation room	Z0404	Treatment	HBN 14-01 (2007)
	20. Aseptic room	Z0303		
	21. Container unpacking & prep	Z0403		
	22. Sterilization	Z0408		
	23. Inspection & labelling	Z0410		

Appendix C.22 Table of 23 departmental room names chosen for scenario creation in Chpater 8 (HBN documents).

Appendix D

4.1.1 Pre 1948: Royal and voluntary hospitals

Appendix D.1 Background to Pre-1600 healthcare and hospital design: On commencing this investigation, the assumption for revolutionary occurrences in British hospital design was sourced around the NHS's establishment (1948). Findings were, however, counterintuitive requiring an alternative and relevant timeframe for Part II's exploration to be determined. This led to a widespread exploration dating back to 400BC as long periods of time existed between milestone events. While only a few pre-1600 revolutionary events emerged, they underpin Part II's exploration of understanding past and present hospital design and the origins of medical planning. Two medical influences - knowledge and practice – were found to be dominant factors of pre-1600 hospital design.

The first medical influence encompasses new medical knowledge, its central position in driving medical progression and other hospital design factors. One major event revolutionised pre-1600 medical knowledge - the writings by Galen of Pergamum (140AD). As per the 16th century physician Theodore Zwinger[1], western medicine had originated in 400BC[2] where the Ancient Greeks had begun practising principles of human wellbeing (Nutton, 2006:47). This knowledge led medical practice throughout Europe for numerous centuries until Galen's radical theories led to the formation of a new medical agenda (van den Berg, 2005:10).. This new 'classical humorism' was a simple model of care that remained unchanged for over fifteen hundred years. As the only method of medical practice during this time, this second medical influence required no specified spatial requirements (Porter, 2006:85). However, considering the innovativeness of humoral thinking it seems unusually significant that no further

---

[1] Zwinger, T. (1533-1588) was a Basle physician and medical professor. In 1570, he traced the ancestry of medicine back to the Greeks in his *Theatrum Vitae Humanae*.

[2] While literature documents medical practice far earlier in ancient Mesopotamia, Egypt, India, China and the Far East, the origins in the thesis refer to Western medicine i.e. Asclepius, Hippocrates and Aristotle.

knowledge was formed for more than a millennium. Literature unanimously attributes the cause of restrictive growth to ecclesiastical dictatorship. Two explanations elucidate the continuation of religious domination.

(i) An integrated relationship between power and medical practice: Under Roman rule (100BC-70AD), only male soldiers and domestic slaves received medical care[3] (Verderber, 2003:286). Therefore, when ecclesiastical care opened its service to all, not surprisingly, this charitable source of healthcare flourished. The outcome created a massive grassroots network that became critical to the Christian Church’s future development. On the collapse of the Roman Empire, the Christian Church, already organisers of the Roman Empire’s official religion, quickly usurped the void in European power[4]. Their expansion became one of ubiquitous domination i.e. throughout finance, education and healthcare (Verderber, 2003:287). For example, medical historian Roy Porter records the Church’s belief ‘in the sanctity of the body’ which, in forbidding the exposition of bodies[5], controlled pathological exploration. As a result, the progress of anatomical knowledge remained stagnated until after the Black Death (1348) (Porter, 2006:136). In a bid to understand the cause of so many fatalities, the Papacy finally allowed for anatomical investigations to take place. This instigated a major revolution that commenced the beginning of contemporary medicine (Barry &, 2005:13-4; Porter, 2006:137).

---

[3] Only a basic level of care was administered to males in *valetudinarians* (100BC-70AD).

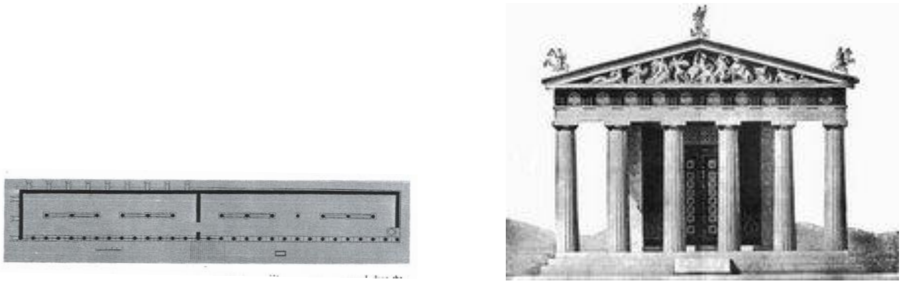
[4] The Christian Church was inaugurated as the official religion of the Roman Empire 313AD (Porter, 2006:55).

[5] As the salvation of souls was paramount to the Christian religion, physical treatment remained insignificance. In fact, as pain and suffering guaranteed a pathway to heaven, spiritual care maintained its status as the main methodology for care until the 1600’s.

4.1.1 Pre 1948: Royal and voluntary hospitals

(ii) Accessibility to knowledge: Far from today's colossal access to information, by the 9th century, access to western knowledge was immensely curtailed by the existence of only one thousand books. Additionally, most of these manuscripts were written in Latin[6] (Nutton, 2006:62). Consequently, limited writings, language barriers and high illiteracy rates all contributed to a restricted dispersion of knowledge. More significantly, the producers of literature were predominantly of the religious orders. They censored all literature in which medical knowledge was embedded, disallowing for medical knowledge and medicine to progress.

Pre-1600 medical practice was similarly experienced in Britain as the rest of Europe. Evidence of religious orders providing limited healthcare is recorded within the Doomsday Book (1086AD) and Mappa Mundi (c.1200AD[7]) (Barry & Carruthers, 2005:5). Therefore, in mapping pre-1600 events, British medical practice was controlled by religious orders until the English Reformation in 1608.



Appendix D.3 Left: The Asclepieion at Epidauros (300BC), the birthplace of Asclepius, was the most celebrated healing centre of the Classical world. Consisting of the *enkoimitiria* (large sleeping hall), ill people would dream for godly advise to restore their health. **Right:** Plan of Asclepieion of Epidauros 5th century BC (Thomson & Goldin, 1975:3).

---

[6] The books in question were illuminated manuscripts i.e. Book of Kells, Ireland. These ornate documents took years to complete, slowing the procedure of reproducing and distributing information.

[7] Mappa Mundi listed all monasteries, castles and waterways that existed at this time. While not of great accuracy prior the medieval period, it is consistently stated that religious orders ran everything. Only a few hospitals were listed, however, the Knights Templar's and Knights Hospitallers were listed as the only hospitals in London (no mention of St Bartholomew's Hospital from 1123).

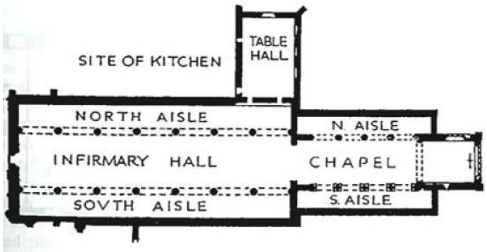
4.1.1 Pre 1948: Royal and voluntary hospitals

Appendix D.2 Gorski, H. (2003) *Remains of the Kos Asclepieion* [Online]. Available at://en.wikipedia.org/wiki/File:Kos_Asklepeion.jpg (Accessed: 18th August 2009).

The impact of healthcare control reflected through to its architecture. No fundamental changes in medical planning were recorded during the Christian Church's reign of power. The architectural status was one of simplicity, which was in keeping with medical knowledge and practice. For example, derived from Ancient Greek temples, monastic infirmaries were arrranged around the simplicity of spirtual care (see Appendix D.2-3). In response, their buildings were simply designed, possessing heavy religious influences, such as, a crucifix form typology that consisted of a large rectilinear open space that was centred on an altar (Verderber, 2003:287; Barry & Carruthers, 2005:3). Reinforcing the insignificance of the physical body, no medical treatment areas existed. Infirmaries had:

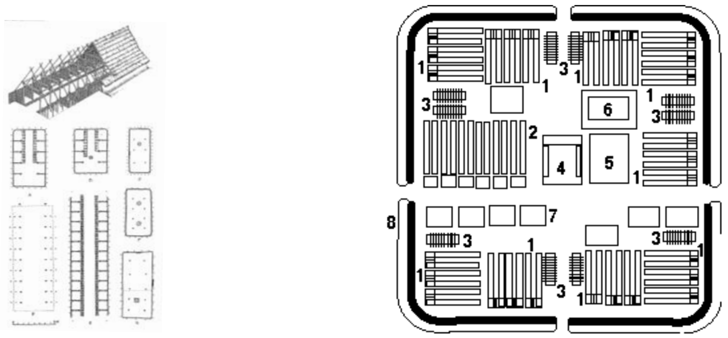
> Developed into buildings with large open wards featuring an alter....to ensure patients could hear and see religious services (Miller & Swennson, 1995:40).

Located centrally or at opposite ends, the alter became the focal point for praying sick patients. This was the only driving factor for internal medical planning of ecclesiastical architecture (see Appendix D.4).



Appendix D.4 Right: 12th century Monastic Infirmary, Canterbury Cathedral (Barry & Carruthers, 2005:1).

4.1.1 Pre 1948: Royal and voluntary hospitals



Appendix D.5 Left: Basic barn structure for patients, 3rd century BC, Netherlands (Thomson & Goldin, 1975:12). **Right:** Plan of a first century fortress (c. 9BC-220AD) 1. Barrack blocks, 3. Granaries, 6. Hospital, 7. Tribunes house.

In Britain, basic healthcare facilities existed since Roman times. Facilities were situated within military forts and fortresses consisting of large open rectilinear rooms (see Appendix D.5):

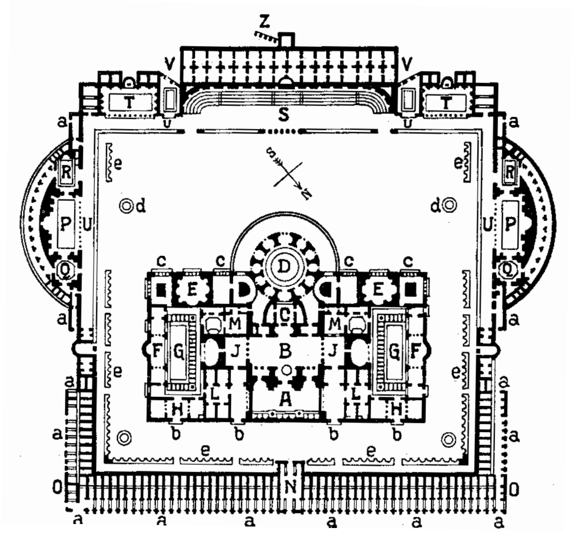
> Large fortress hospitals, as at Chester (England) or Inchtuthil (Scotland), were for legionaries (not locals), and were designed on a plan of rooms opening off a square corridor. Situated usually many miles behind the frontier, they catered for the sick....but a change in military strategy around 220 to reliance on a mobile fieldforce put an end to these permanent hospitals (Porter, 2006:54).

When the Roman Empire fell, the UK was thrown into the Dark Ages (400AD-1050AD). Innovation, new knowledge and hospital architecture all ceased with existing timber structures disintergrating. However, the thesis acknowledges one significant pre-1600 typology - the Baths of Caraculla dating 250AD. In response to Galen’s theories, the Romans developed a highly sophisticated architectural response to wellbeing. At Caraculla, the design was intented purposely to exercise mind, body and soul. It included the segregation between male and female as well as hot and cold treatments. Spaces were appointed functionally for the separatation of treatments i.e. *frigidarium* for fitness, hot bath for sweating or libraries for knowledge[8] (Furneaux Jordan, 1991:52-4). This high level of complexity is the basis from which this thesis considers the Baths of Caracalla to be the first revolution in medical planning (see Appendix D.6).

---

[8] Based upon classical humorism, the practice of sweating was part of cleansing the bodies’ homours.

4.1.1 Pre 1948: Royal and voluntary hospitals



BATHS OF CARACALLA

A.	Frigidarium (Swimming Pool)
B.	Great Hall
C.	Nymphaeum
D.	Calidarium
EE.	Lounges
FF.	Lecture Halls
GG.	Palaestra
HH.	Vestibules
JJ.	Courts
LL.	Dressing Rooms
MM.	Steam Baths
N.	Main Entrance
OO.	Shops
PP.	Gymnasia
QQ.	Nymphaea
RR.	Study Rooms
S.	Steps to Portico
TT.	Libraries
UU.	Promenades
VV.	Cisterns
Z.	Aqueduct and Reservoir
aa.	Façade of External Enclosure
bb.	Entrance to the Baths
cc.	Game and Sport Rooms
dd.	Fountains
ee.	Podia of Colonnades

Appendix D.6 Baths of Caraculla (250AD) organised different treatments and ailments through the use of sophisticated planning and technology (Furneaux Jordan, 1991:53).

Aside the Baths of Caraculla, it became apparent that pre-1600 hosptial design development was rather non-eventful specifically with relevance to technology's influence upon space. While great strides occurred in architecture i.e. Romanesque and Gothic architecture, the medical planning of hospitals remained stagnated until 1600. A synopsis of this section establishes:

(i) Ecclesiastical care directly influenced medical knowledge, practice and hospital design that resulted in no specialised spaces for medical treatments

(ii) Infirmary numbers increased but innovation was not present

(iii) A simple open plan with no medical planning issues existed until 1600 (except the Baths of Caracalla).

4.1.3 Analysis of organisational findings

Location	**A.** Type of Organisation	**B.** Internal influences	**C.** External influences
1. Ancient Greece	Greeks	Gods and priests	None
2. Roman Empire	Christianity	Ecclesiastical power	Took control of care, powerful political
3. UK	Reformation	Ecclesiastical care ceased	UK Crown policy closed all down.
4. UK	Royals	New organisation (fee paying)	UK Crown policy.
5. UK	Voluntary	Governors and powerful clinicians (freecare)	Charity
6. UK	NHS	NHS management	1946 NHS Health Act.
7.UK	NHS/PFI	PFI transfers ownership and control of estates.	NHS 2000 Plan,

Appendix D.7 Tabled events of organisational influences in hospital design dating 400BC-date.

Location	**A.** Type of Organisation	**D.** Architectural Impact	**E.** Architectural Analysis	**F.** Org. Analysis
1. Ancient Greece	Greeks	Asclepeions	Influential	Volumes rather than innovation
2. Roman Empire	Christianity	Building of monastic infirmaries	Numeric rather than innovative	
3. UK	Reformation	All closed down.	Huge political influence. All closed	All closed down.
4. UK	Royals	Only hospitals in London after 1700. Rented in Palladian styled buildings.	Mainly rented.	Important
5. UK	Voluntary	Rental properties. No new typologies until Nightingale Wards.	Rented first but were later built.	
6. UK	NHS	No new buildings until late 1960's hospital building programme	Influential only when money is available	Not significant
7.UK	NHS/PFI	Cost driven, PFI hospital building programme	Influential only when money is available	Yes -PFI ownership

Appendix D.8 Tabled events of organisational influences in hospital design dating 400BC-date.

4.2.5 Analysis of medical influences

			400BC-2010		Post 1600		Post 1800	
No. of events		**Revolution**	**Year**	**% of time frame**	**% of events**	**% of time frame**	**% of events**	**% of time frame**
	1	Ancient Greek	400BC-140AD	22.4	44.4	83	77.7	91.2
	2	Galen's Theories	140AD -1600	60.6				
	3	Black death - exposition	1400s	4.1				
	4	Printing	1500s	4.1				
	5	Renaissance	1600s	4.1	55.6	17		
	6	Industrial Revolution	**1850**	4.1				
	7	European institutions	1700s	4.1				
	8	Teaching hospitals	1800s	4.1			22.3	8.8
	9	C20th development	1900s	4.1				
Total	**9**		2410		100	100	100	100

Appendix D.9 Medical Knowledge: Events/revolutions? and timeframes of revolutions for the development of medical knowledge.

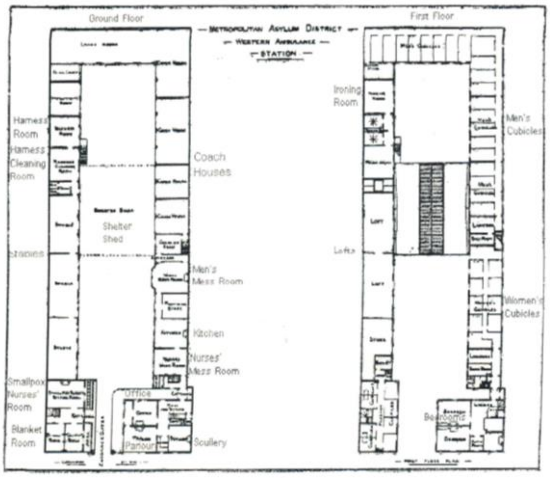
			400BC - 2010		Post 1600		Post 1800	
No. of events		**Revolution**	**Year**	**% of time frame**	**% of events**	**% of time frame**	**% of events**	**% of time frame**
	1	Galen's Theories	140AD -1850	60.6	33.3	83	33.3	91.2
	2	Clinical Gaze	1850s	6.6	66.7	17	66.7	8.8
	3	Acute Care	1930s	3.3				
Total	**3**		2410		100	100	100	100

Appendix D.10 Medical practice: Table of listed timeframes and revolutions for medical practice.

4.2.5 Analysis of medical influences

			400BC-2010		Post 1600		Post 1800	
No. of events		Revolution	Year	% of time frame	% of events	% of time frame	% of events	% of time frame
	1	Royal & Voluntary hospitals	1600-1948	14.4	100	17	20	91.2
	2	Public Health Act	1879	2.5			80	8.8
	3	Emergency Medical Service Act	1939					
	4	NHS	1946	2.6				
	5	Patient Charter	1991	0.08				
	6	Technology & Internet	1990s	0.08				
Total	**6**		2410		100	100	100	100

Appendix D.11 Medical Delivery of care: Revolutions and timeframes of revolutions for the delivery of care



Appendix D.12 Western Ambulance Station, London 1891 (Higginbotham, 2010).

4.2.5 Analysis of medical influences

			400BC-2010		Post 1600		Post 1800	
No. of events		**Revolution**	**Year**	**% of time frame**	**% of events**	**% of time frame**	**% of events**	**% of time frame**
	1	Separated	400BC-140AD	22.4	66.6	83	66.6	91.2
	2	Non-separated	140-1850s	71	33.3	17	33.3	8.8
	3	Separated	1850s+	6.6				
Total	**3**		2410		100	100	100	100

Appendix D.13 Medical Processes of care: Revolutions and timeframes of revolutions for the development of medical processes.

	Medical Influence	**No. of event**	**What were they**	**No. of rev.s**	**What were they**
4.2.1	Knowledge	9	1. Ancient Greek 2. Galen's Theories 3. Black death – exposition 4. Printing 5. Renaissance 6. Industrial Revolution 7. European institutions 8. Teaching hospitals 9. C20th development	6	1. Ancient Greek to Galen's Theories 2. C16th - exposition of bodies 3. Improved Communications 4. Industrial Revolution 5. Hospitals-teaching hubs 6. C20th pharmaceuticals
4.2.2	Practice	3	1. Galen's theories 2. Clinical Gaze 3. Acute care	1	Change in agenda (1850s).
4.2.3	Delivery	6	1. Establishment of Voluntary/ Royal hospitals 2. *1879 Public Health Act* 3. *1939 EMS Act* 4. *1946 NHS Act* 5. *1991 Patient Charter* 6. Technology/Internet	5	1. Change in organisation power of delivery 2. New spaces in hospitals for ambulances 3. Introduction of acute care 4. Mobility of care
4.2.4	Processes	3	1. Non-separated care 2. Separated care 3. Non-separated care	3	Change in process methodology

Appendix D.14 Medical influences: Historical summary of events and revolutions.

4.2.5 Analysis of medical influences

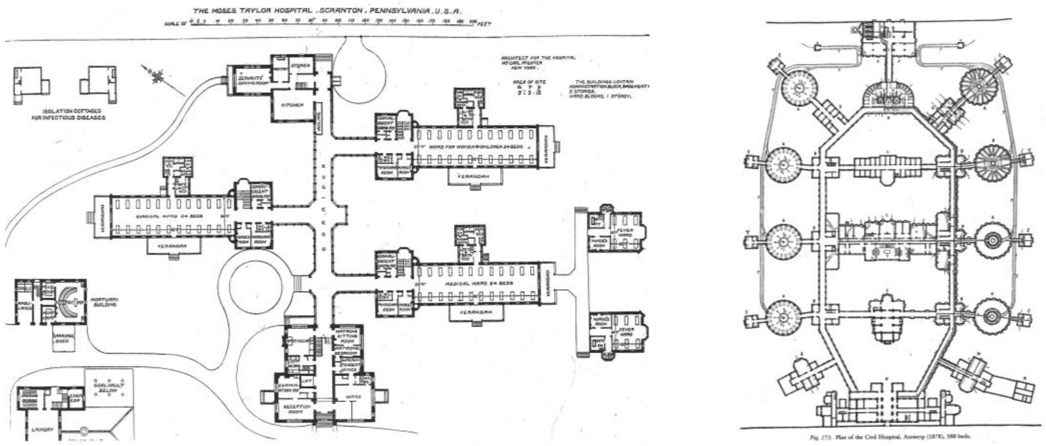
				Post 1600		Post 1800	
No. of influences		**Medical influence**	**No. of events**	**No. of events**	**% of time frame**	**No. of events**	**% of time frame**
	1	Knowledge	9	5	17	2	8.8
	2	Practice	3	2		2	
	3	Delivery	6	6		5	
	4	Processes	3	1		1	
Total	**4**		21	14	17	10	8.8

Appendix D.15 Table of events and % timeframes for all medical influences.

Medical influence	Post 1600		Post 1800		Analysis
	Events%	**%Time**	**%Events**	**%Time**	
Knowledge	55.6	17	22.3	8.8	Events have been increasingly numerous since 1600.
Practice	66.7		66.7		Events have only occurred since 1800.
Delivery	100		80		Large amount of events have occurred since 1600 and particularly since 1800.
Process	33.3		33.3		A small amount of events but create radical change once introduced. Has only happened since 1800.

Appendix D.16 Medical design influences and their relationships.

4.3.1 16th – 20th century hospitals: The source of revolutionary hospital designs



Appendix D.17 Exemplar plans of pavilion type typologies **Left:** Plan of Moses Taylor Hospital, Scranton, Pa. **Right:** Plan of the Civil Hospital, Antwerp (1878), 388 beds (Thomson & Goldin, 1975:166-7).

4.3.1 16th – 20th century hospitals: The source of revolutionary hospital designs

Year	Act title	Government	Description of Act	Architectural implication
1911	National Insurance Act	Liberal coalition	Employee contributions reduce the amount of people depending on poor law provisions.	With more patients going to hospital more space is required (OPD)
1941	Emergency Medical Service	Conservative	Allowed medical staff to work between voluntary and municipal hospitals.	Changed the organisation of London's hospitals.
1946	National Health Service Act	Labour	Creation of NHS/ Rationalization of organisation.	Only refurbishments until the 1962 Hospital Plan
1962	The Hospital Plan	Conservative	£500M for the building of new 600 bed DGH's	233 new and upgraded hospitals
1966	Regulation 22 of the National Health Service	Labour	Charter for the Family Doctor Service	Building of numerous centres
1991	The Patient's Charter	Conservative	Respecting patient privacy and patient focused care	Better environments, universal room i.e. Kingston hospital
2000	NHS Plan 2000	Labour	Introduction of 100% single bedrooms	Change in typological form

Appendix D.18 Analysis of Public Health Acts, 1900-2010.

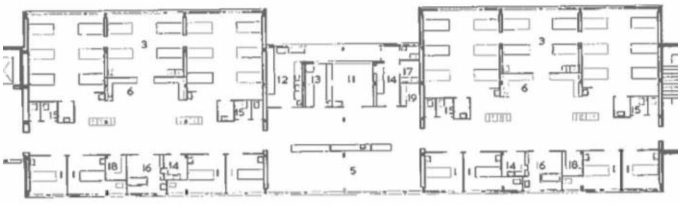
Year	Legislation passed	Government type	Legislation description	Architectural responses to legislation
1866	Sanitation Act	Conservative	Local health boards became responsible for clean water.	All new buildings to have closed water closets.
1853	Compulsory Vaccination Act	Conservative	All citizens were to be vaccinated against Smallpox.	Reduced area for treating smallpox
1875	Public Health Acts	Conservative	Running water and internal sewers	New annexes in hospitals
1879	Public Health Act	Conservative	New ambulances, to take contagious patients to hospital.	Added area required for admissions.

Appendix D.19 Analysis of Public Health Acts, 1850-1900.

4.3.2 Early-20th century hospitals

Appendix D.20 Exemplars of sanatorium hospitals[9] (National Archives, 1949; University of Rochester Medical Centre, 1920s).

4.3.3 British Hospital Design Resarch (HDR)



Appendix D.21 Ground floor plan, Nuffield House, Musgrave Park Hospital, Belfast. This new conceptual layout for a ward template design replaced the Nightingale Ward with a 6 bedded bay ward. Based upon research conducted by Nuffield Trust, this design was tested for functionality at Musgrave Park Hospital. This model was later known as the Nuffield Ward (Monk, 2004:10).

Perspective, Swindon Hospital
Wexham Park Hospital, Slough
High Wycombe Hospital

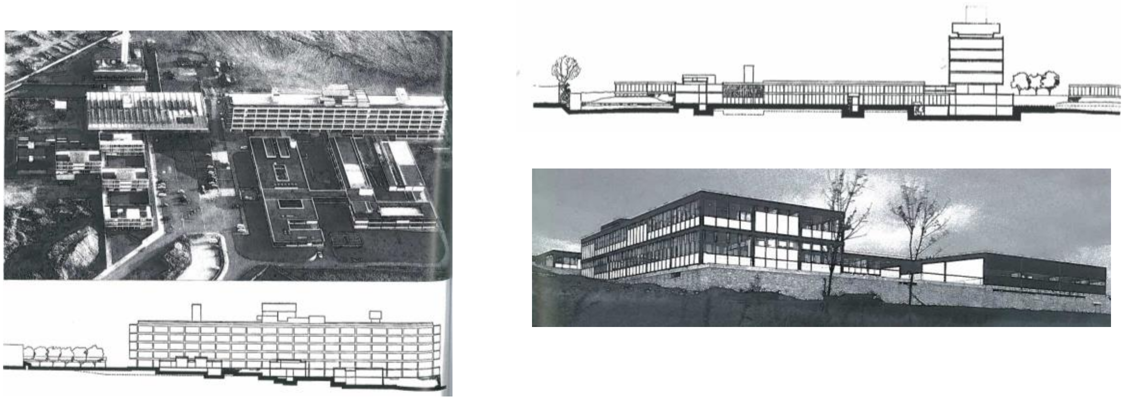
1959 **1966** **1966**

Appendix D.22 Typological examples by Powel & Moya Architects. Swindon was the first large NHS general hospital that used HBNs (Monk, 2004:11). However, only one HBN for Wards existed at the time (Weeks, 1999:15). Powell & Moya's designs were heavily supported by the *Studies in the function and design of hospitals.* High Wycombe Wards consisted of 4-6 bed Nuffield units, of racetrack principle which were located around a central circulation core. D&T departments were located at ground and first level floors while services were located under the car park (Monk, 2004:11).

---

[9] Left: National Archives (1949) *In 1949 child patients at Braintree Hospital in Essex are lined up for school lessons*. Right: *Patients at the J.N. Adam Memorial Hospital , a tuberculosis sanitarium south of Buffalo, N.Y 1920.*

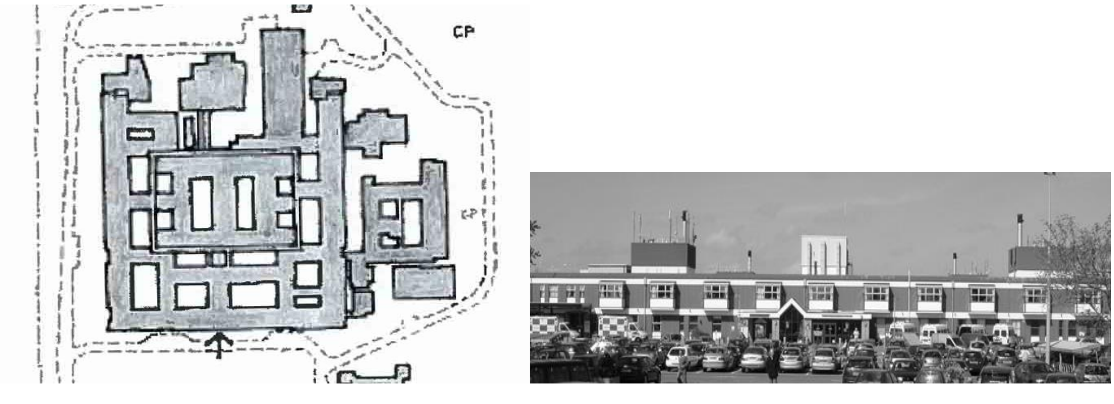
4.3.3 British Hospital Design Resarch (HDR)



Appendix D.23 View, section, aerial view of Swindon hospital, Powell and Moya Architects (1959) (Monk, 2004:48).

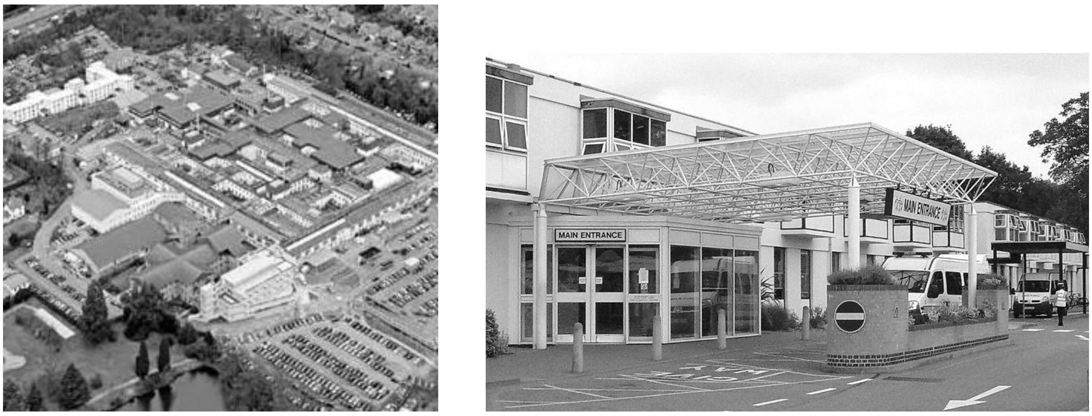
Appendix D.24 Wexham hospital (1950s). 1st type horizontal planning, new ideas, 300 bed (Monk, 2004:59).

4.3.4 Typological outcomes of British HDR (1960s-2000)

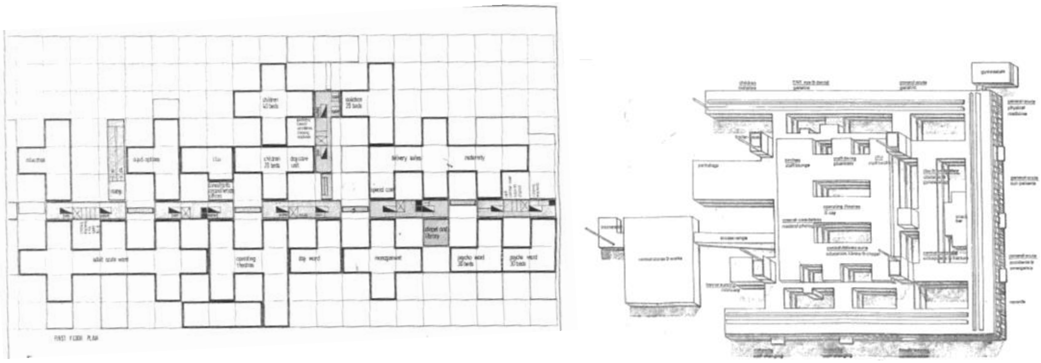


Appendix D.25 Best Buy: Bury St Edmunds Hospital (Smyth et. al., 2006:10).

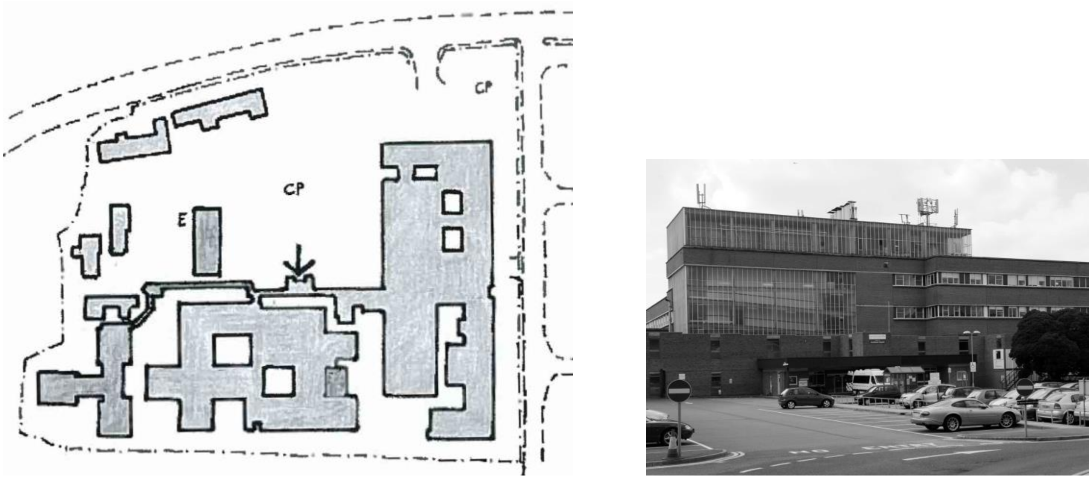
4.3.4 Typological outcomes of British HDR (1960s-2000)



Appendix D.26 Best Buy, Frimley Hospital. Two storey, modular form pierced with internal courtyards for daylight. The *Mark I* version, which ‘was designed to be built in one phase as a hospital of 500-600 beds’ (Watkin, 1978:66; Euchiasmus, 2012).

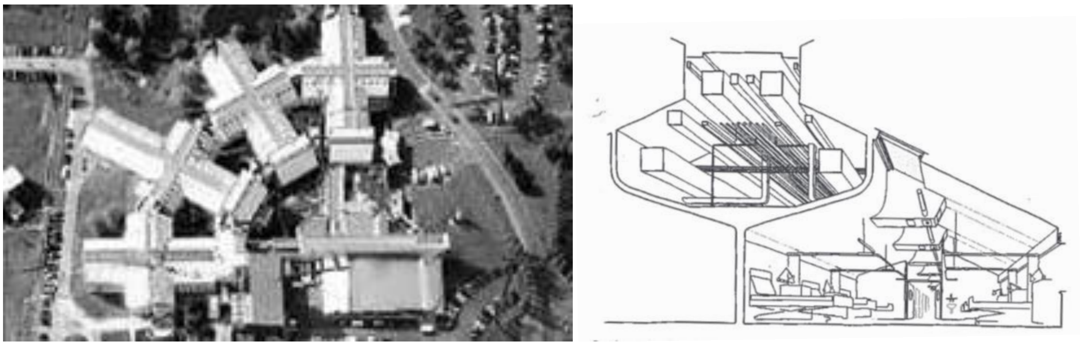


Appendix D.27 Left: ‘Best Buy’ plan (Noakes, 1982:127). **Right:** ‘Best Buy’ hospital by DHSS and COI 1973 (Moss, 1978:11).



Appendix D.28 Left Harness: Southlands, Shoreham-on-Sea, Hospital Design Partnership (Smyth et. al., 2006:41). **Right:** The Harness model, Southlands hospital (Ryan, 2013).

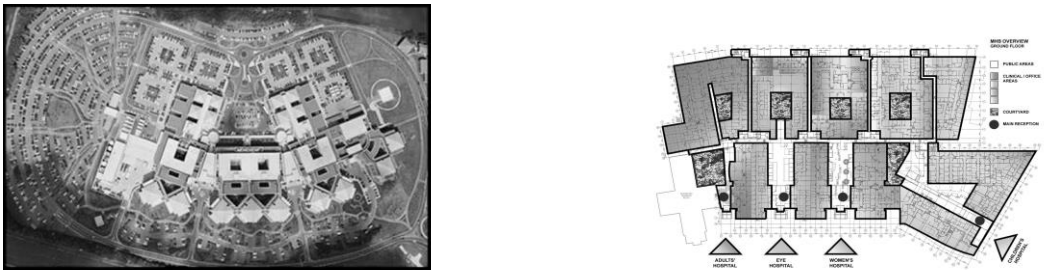
4.3.4 Typological outcomes of British HDR (1960s-2000)



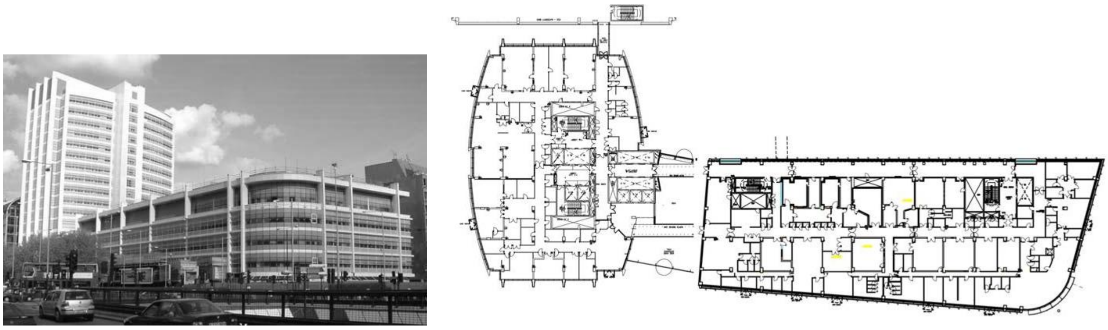
Appendix D.29 St Mary's, IOW by Ahrends Burton Koralec (ABK) (Monk, 2004:12-3)

4.3.5 Post 1990s: PFI

Appendix D.30 Left:1:200 drawing, Pembury Acute and W&C's Hospital, RTKL (2006). **Appendix D.31 Mid-Right:** Oxford Radcliffe Hospital, RTKL (2006).



Appendix D.32 Left: Norfolk and Norwich Hospital, 1st PFI, Anshen and Allen (1999). **Right:** Manchester Acute Hospital, Anshen & Allen (2007).

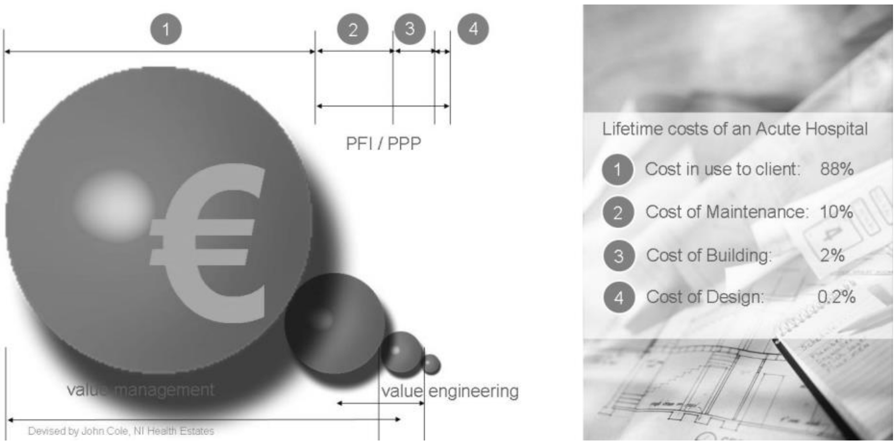


Appendix D.33 UCLH, Euston Road, London, LD (2005).

4.3.6 Analysis of architectural influences

	Act title	Govern-ment	Description of Act	Architectural implication
1911	*National Insurance Act*	Liberal coalition	Employee contributions reduce the amount of people depending on poor law provisions.	With more patients going to hospital more space is required (OPD)
1941	*Emergency Medical Service*	Conser-vative	Allowed medical staff to work between voluntary and municipal hospitals.	Changed the organisation of London’s hospitals.
1946	*National Health Service Act*	Labour	Creation of NHS/ Rationalization of organisation.	Only refurbishments until the 1962 Hospital Plan
1962	*The Hospital Plan*	Conser-vative	£500M for the building of new 600 bed DGH’s	233 new and upgraded hospitals
1966	*Regulation 22 of NHS*	Labour	Charter for the Family Doctor Service	Building of numerous centres
1991	*The Patient’s Charter*	Conser-vative	Respecting patient privacy and patient focused care	Better environments, universal room i.e. Kingston hospital
2000	*NHS Plan 2000*	Labour	Introduction of 100% single bedrooms	Change in typological form

Appendix D.34 Tabled analysis of legislation: 1900-2010. (Watkins, 1978:58-70).



Appendix D.35 Lifetime costs of hospital buildings (John Cole, NI Health Estates).

4.4 Chapter analysis

				Post 1600		Post 1800	
No. of influences		**Architectural influence**	**No. of events**	**No. of events**	**% of time frame**	**No. of events**	**% of time frame**
	1.	Pre-16th	4	0	17	0	8.8
	2.	16th-20th	4	4		3	
	3.	Early-20th	6	6		6	
	4.	British HDR	8	8		8	
	5.	HDR/PFI results	4	4		4	
Total	**5**		26	22	17	21	8.8

Appendix D.36 Events and revolutions: Timeframes of revolutions for architectural influences.

	Arch. Influence	**No. of events**	**What were they**	**No. of revolu-tions**	**What were they**
4.3.1	16th-20th	4	1. Obliteration of ecclesiastical typologies 2. Rented accommodation 3. Nightingale ward/pavilion typology 4. Architectural developments	2	From the deletion of hospitals to the creation of a whole new generation of hospitals
4.3.2	Early-20th	6	1. Sanatoriums 2. Improved services 3. Deep-space planning 4. Departmental segregation 5. Amalgamation of NHS and specialist hospitals 6. Matchbox-on-a-muffin	6	Changes to hospital architecture, typology and medical planning
4.3.3	British HDR	8	1. *Studies in the function and design of hospitals* 2. Nuffield Ward 3. HBN documentation 4. Hospital street 5. MOH HDR 6. Automated hospital 7. Powell & Moya works 8. Greenwich Hospital	4	Changes to hospital architecture, typology and medical planning
4.3.4 -5	Results of HDR/PFI	4	1. Best-buy model 2. Harness model 3. Nucleus model 4. PFI programme	4	Changes to architecture, typology, medical planning

Appendix D.37 Architectural influences: Historical summary of events and revolutions.

Appendix E

5.0 Introduction

	Spatial description	Spatial dimensions mm	Area sqm		Reference
1	Space for storage (high level)	400 x 1000	0.40	**Total:** 2.00	HBN 00-03:82
	Space for standing at storage (high level)	1600 x 1000	1.60		HBN 00-03:82
2	Space for storage (low/full level)	700 x 1000	0.70	**Total:** 2.30	HBN 00-03:82
	Space for standing at Storage (low/full level)	1600 x 1000	1.60		HBN 00-03:82
3	Workspace bedside sink	800 x 650	0.52		HBN 00-03:48
4	Space for kitchen sink	600 x 650	0.39		HBN 00-03:48
5	Space for office workstation		5.00		HBN 00-03:55
6	Space for quiet work	1400 x 1600	2.24		HBN 00-03:57
7	Space for ambulant seated person (waiting)		1.5 (each) x 9 = 13.5 (per waiting area)		HBN 00-03:88
8	Space for seated wheelchair (waiting)		3.0 (each) x 3 = 9.0 (per waiting area)		HBN 00-03:88
9	Space for child play (waiting)		2.0 (each) x 3 = 6.0 (per waiting area)		HBN 00-03:88
10	Space for office workstation	2000 x 2250	5.00		HBN 00-03:90
11	Space for photocopying	2400 x 2500	6.00		HBN 00-03:90
12	Space for wash-hand basin (WHB)	900 x 400	0.36	**Total:** 1.08	HBN 00-03:64
	Space for standing at wash-hand basin (WHB)	900 x 800	0.72		HBN 00-03:64
13	Space for patient on couch (single assisted)	2800 x (650+800+100)	4.34		HBN 00-03:70
14	Space for patient on couch (dual assisted)	2450 x 2800	5.25		HBN 00-03:71
15	Space for patient on treatment chair	1900 x 900	1.71		HBN 00-03:72
16	Space for patient on treatment chair with space for changing	2800 x 1000	2.80		HBN 00-03:72
17	Space for patient on treatment chair with space for examining	2800 x 800	2.24		HBN 00-03:72

18	Space for patient on Kings Fund bed	1060 x 2335	2.48	HBN 40(2):30
19	Space for Kings Fund bed movement (dual)	2150 x 2335	5.02	HBN 00-03:60, HBN 40(2):30
20	Space for shower	2700 x 2700	7.29	HBN 40(2):56
21	Space of WC	1650 x 2350	3.88	HBN 40(2):49
22	Space for Assisted WC (AWC)	1900 x 2350	4.47	HBN 40(2):47
23	Space of treatment room	3700 x 4500	16.65	HBN 40(2):24
24	Space of consult/exam room	4900 x 3500	17.15	HBN 40(2):17
25	Space for person standing/walking x2	1000 x 1200	1.20	HBN 40(1):21, HBN 40(2):61
26	Space for standing person	1000 x 1000	1.00	HBN 40(2):61
27	Space for doctor (standing) treating patient	1000 x 1000	1.00	HBN 40(2):61
28	Space for assisted (x 2) person standing/ walking	1000 x 1600	1.60	HBN 40(1):22, HBN 40(2):61
29	Space for seated person on chair	1400 x 700	0.98	HBN 40(2):60
30	Space for assistance beside chair (single)	1400 x 600	0.84	HBN 40(2):60
31	Space for chair and assistance (single)	1700 x 1500	2.55	HBN 40(2):60
32	Space for patient on operating table & workspace (google)	2150 x 4000	8.60	HBN 26:76
33	Space for sitting at workstation	1000 x 900	0.9	HBN 00-03:68
34	Space for workstation	1000 x 700	0.7	HBN 00-03:68
35	Workspace beside workstation	1000 x 700	0.7	HBN 00-03:68

Excludes circulation 5% planning, 3% engineering or 22% circulation.

Appendix E.1 Table of HBN spatial dimensions and area calculations for quantitative spatial analysis throughout research.

5.1 Pre-electrification technology

Appendix E.2 Hybrid OR – Cardiac Operating Theatre with Catheter Laboratory (Cath. Lab.), Nationwide Children’s Hospital, Columbus, Ohio, NBBJ Architects.

5.1.1 Growth of microscopy (post-1800s)

Date	Event	Pioneer
C17th	Invention of microscope (Porter, 2006:140)	Antoni van Leeuwenhoek -The Netherlands
C17th	Development of bacteriology	Robert Hooke (UK), Antoni van Leeuwenhoek, Marcello Malphigi
1745	Experimented	Dr. John Needham, England
1837	Outlined germ theory for fermentation, and founder of cell theory in biology	Physician, Theodor Schwann, Germany
1840	Published a widely read essay on miasma and contagion, listing diseases he thought were miasmal or contagious	Anatomist, Jakob Henle, Germany
1857-63	Pioneer of germ theory & bacteriology. Huge benefits for public health and medical sciences.	Chemist, Louis Pasteur, France
1871	Penicillin is found to help with the recovery of wounds	Surgeon, Joseph Lister, England
1843–1910	Work published under Cohn's guidance (1876). New science of bacteriology (the first exact medical science) that isolating bacteria and differentiated them.	Medical officer, Robert Koch, Poland
1881- 85	Anti-rabies vaccine discovered	Chemist, Louis Pasteur, France
1887	Petri dish invented	Richard Petri

Appendix E.3 Events in bacteriology (Crawford, 2005).

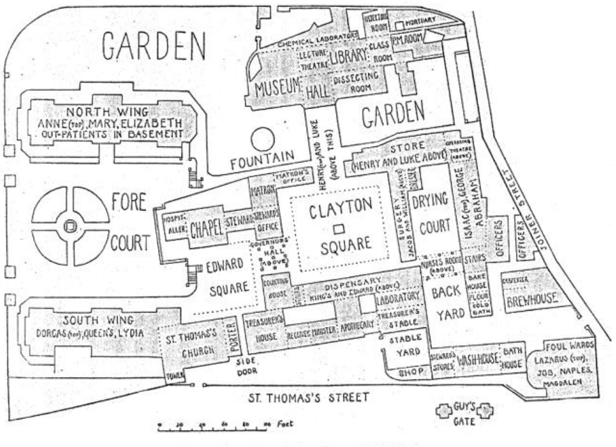
5.1.1 Growth of microscopy (post -1800s)

Date	Event	Pioneers
C17th	Using a primitive, single-lens microscope, observed red blood cells (erythrocytes) as the size of a grain of sand (Corliss, 2002).	Microscopist Antonie van Leeuwenhoek, Holland
18th century	Amplified the description of red cells and demonstrated the role of fibrin in the clotting (coagulation) of blood (T.S.W, 1934).	Physiologist, William Hewson, England.
19th century	Bone marrow was recognized as the site of blood-cell formation. Along with the first clinical descriptions of pernicious anaemia, leukaemia, and a number of other disorders of the blood (Porter, 2006:156-63).	General
Post World War II	Field of haematology broadens. Studies revealed haemoglobin variations causes disease i.e. sickle cell anaemia. Advances in techniques of protein and enzyme chemistry identified genetic disorders, such as, leukaemia (Porter, 2006:165-72).	General

Appendix E.4 Events in haematology.

Date	Event	Pioneers
Late C18th/ early C19th	Knowledge about enzymes and metabolism discovered (Porter, 2006:165-72).	General
1903	Accepted that the word ‘biochemistry’ was first proposed by European Association for Chemical and Molecular Sciences. EuCheMS.	Carl Neuberg, Chemist,Germany
1914	Department of Biochemistry opens at Cambridge University, UK.	Cambridge, UK.
1950s	Biochemistry advances, such X-ray diffraction and electron microscopy. Helical model of mucleic acid discovered (My Agriculture Information Bank, 2013).	Watson and Crick

Appendix E.5 Events in biochemistry.



PLAN OF ST. THOMAS'S HOSPITAL, ABOUT 1853

Appendix E.6 Distributed laboratories, St. Thomas’, 1853 (Barry & Carruthers, 2005:35).

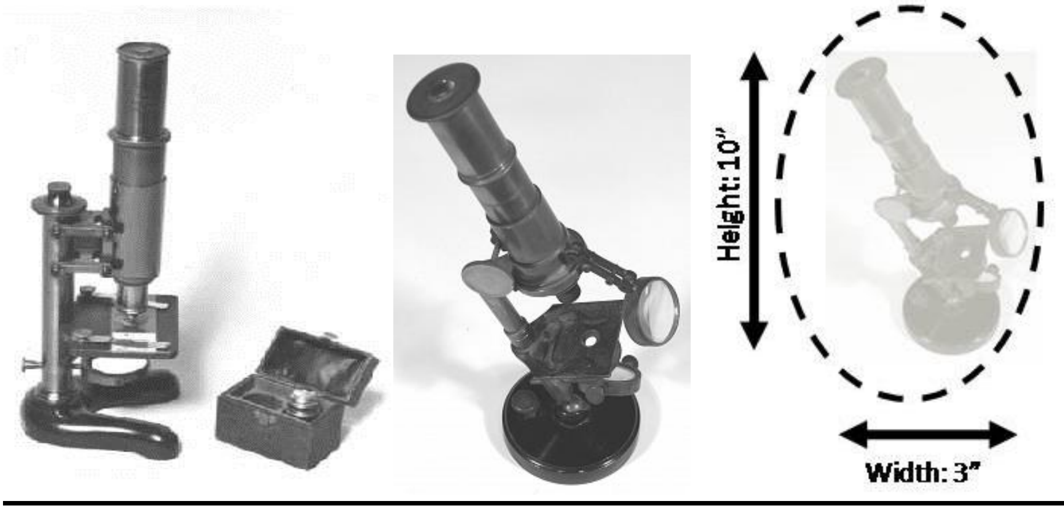
5.1.1 Growth of microscopy (post-1800s)

‘Considered the “father of microscopy”, he constructed all his own equipment using lenses he had made himself....The specimen to be studied is placed on the pin and is brought into focus on the small lens by adjusting the two screws. The glass lens is fixed between two brass plates. The microscope would have been difficult and uncomfortable to use as the eye would have to be placed very close to the lens to make any observations. Lighting the specimen would also have been difficult’.

Appendix E.7 *Leeuwenhoek simple microscope (copy), Leyden, 1901-1930. Science Museum London* [Online]. Available at: http://www.sciencemuseum.org.uk/broughttolife/objects/display.aspx?id=4740 (Accessed: 1st May 2012).

‘Oliver Wendell Holmes began to offer instruction in microscopic anatomy at the Tremont Street Medical School in the late 1840s and was offering practical instruction in the use of the microscope to medical students at Harvard by 1855.’

Appendix E.8 *Oliver Wendell Holmes with his Microscope: albumen print, circa 1860. The Collections of the Boston Medical Library* [Online]. Available at: https://www.countway.harvard.edu/chm/rarebooks/exhibits/broad_foundation/broad_foundation3.html (Accessed: 1st May 2012).



Appendix E.9 Left: *Compound microscope*, E. Leitz, Wetzlar, Germany, 1894 (University of Sydney, 2012). **Middle-Right:** Microscope (1880): 10” high on a 3” base with mirror, specimen stand with lyre shaped holder, three apertures between stand and mirror, single barrel 6” long with screw focusing, magnifying glass attached to mirror on swivel mount, on objective and eyepiece, no case (Museum of Historical Medical Artifacts, 2012a).

5.1.1 Growth of microscopy (post-1800s)

Left: Appendix E.10 Dr. Henry Fisher examines specimen, Pathology Lab, c.1890s (University of Pennsylvania, 2012). **Right: Appendix E.10a** Spatial analysis of Appedix E.10.

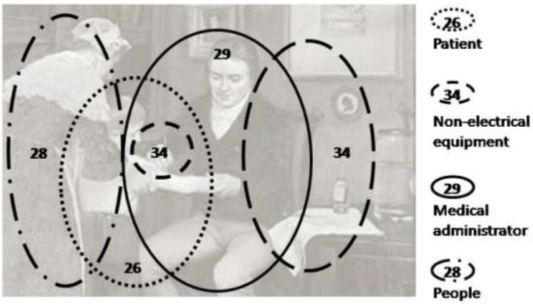
Microscope Area: 0.019sqm (10" x 3"/0.254m x 0.0762m)			
No. & Description of Spatial Functionality		**Functional Area sqm**	**Functional area type**
34	Space for bench mounted piece of equipment (area for microscope included)	0.7	Equipment, Workspace
33	Space for microscope operator in sitting position	0.9	Person
34	Space for workspace either side of equipment x 2	1.4	Workspace
2	Space for storage full height x 2	4.6	Storage
	Total/piece of equipment	7.6	
	Equipment: Area ratio	1:400	

Appendix E.11 Table of spatial analysis: Microscope equipment.

5.1.2 Development of vaccinations (1796)

Left: Appendix E.12 Two antique syringes from the late 1800s show evidence of the requirements for sterilization: they are entirely made of metal or glass (Memorial Hall Museum Online, 2012). **Middle & Right:** Whittemores vaccinator, 2.25"x 0.75" body with a finger loop as part of the assembly, manufactured by Codman and Shurtleff (1866) (Museum of Historical Medical Artifacts, 2012b).

5.1.2 Development of vaccinations (1796)



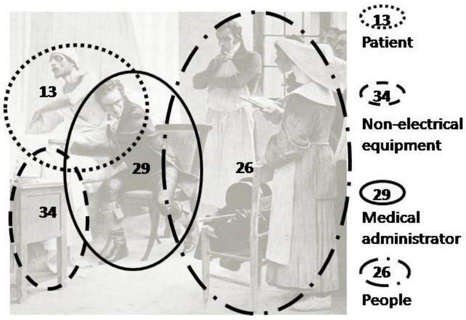
Left: Appendix E.13 Sample 2: Pictorial evidence of Jenner performing his first vaccination (Board, 1912). **Right: Appendix E.13a** Spatial analysis of Appendix E.13.

Vaccinator Area: 0.00108sqm (0.75” x 2.25”/0.01905m x 0.05715m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
26	Space for person standing	1.00	Person
29	Space for a seated administrator	0.98	Person
28	Space for administrator’s assistant	1.60	Workspace, Person
34	Space for workspace (inc. syringe)	0.70	Workspace, Equipment
	Total/person	4.28	
	Equipment: Area ratio	1:3963	

Appendix E.14 Table of spatial analysis: Vaccinator equipment.

5.1.3 Patient observation and the stethoscope (1816)

Left-middle: Appendix E.15 Laennec's stethoscope Credit: Science Museum/Science & Sorbonne’ Society Picture Library (Porter, 1996:174). **Right: Appendix E.15a** Stethoscope, Piorry (1830) which has a 7” long oak stem and 0.65” diameter.



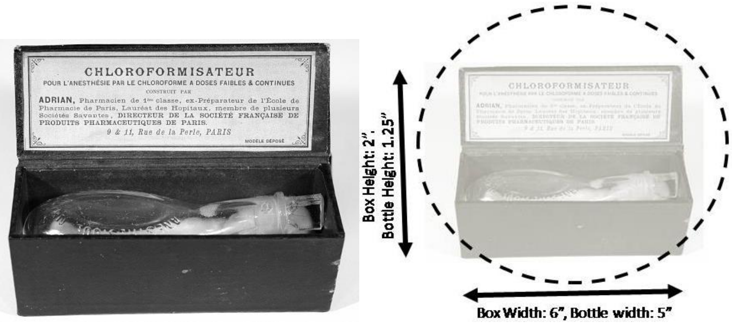
Left: Appendix E.16 1816, Rene Laennec invents the first stethoscope by Chartan in the Sorbonne (Porter, 1996:174). **Right: Appendix E.16a** Spatial analysis of Appendix E.16.

5.1.3 Patient observation and the stethoscope (1816)

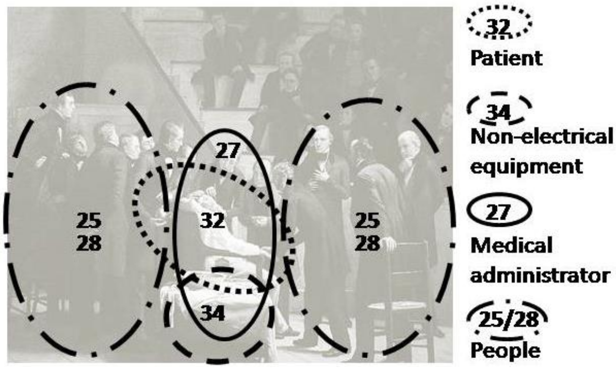
Stethoscope Area: 0.0038sqm (0.23m[1] x 0.01651m[2])			
	Spatial Functionality	**Area sqm**	**Functional area type**
13	Space for patient on couch (single assisted)	4.34	Person
29	Space for an administrator	1.00	Person**,** Workspace
26	Space for administrator’s assistant	1.00	Person, Workspace
26	Space for numerous spectators x 4	4.00	Person
34	Space for workspace (inc. stethoscope)	0.70	Workspace, Equipment
	Total/person	11.04	
	Equipment: Area ratio	1:2905	

Appendix E.17 Table of spatial analysis: Stethoscope equipment.

5.1.4 Use of anaesthesia and sterilisation (post-1840s)



Appendix E.18 Left: *Surgery before anaesthesia*, circa 1840s, (Barry & Carruthers, 2005:140). **Middle & Right: Appendix E.18a** *Chloroformisateur* by Adrian, Paris (1890). 6“ x 2“ x 2” black box contains a 5” x 1.25“x 1.75” bottle like a nurser with a glass stopper (Museum of Historical Medical Artifacts, 2012d).



Right: Appendix E.19 First operation performed under ether anaesthesia in 1846 painted by Robert C. Hinkley (Porter, 1996:228).
Left: Appendix E.19a Spatial analysis of Appendix E.19.

---

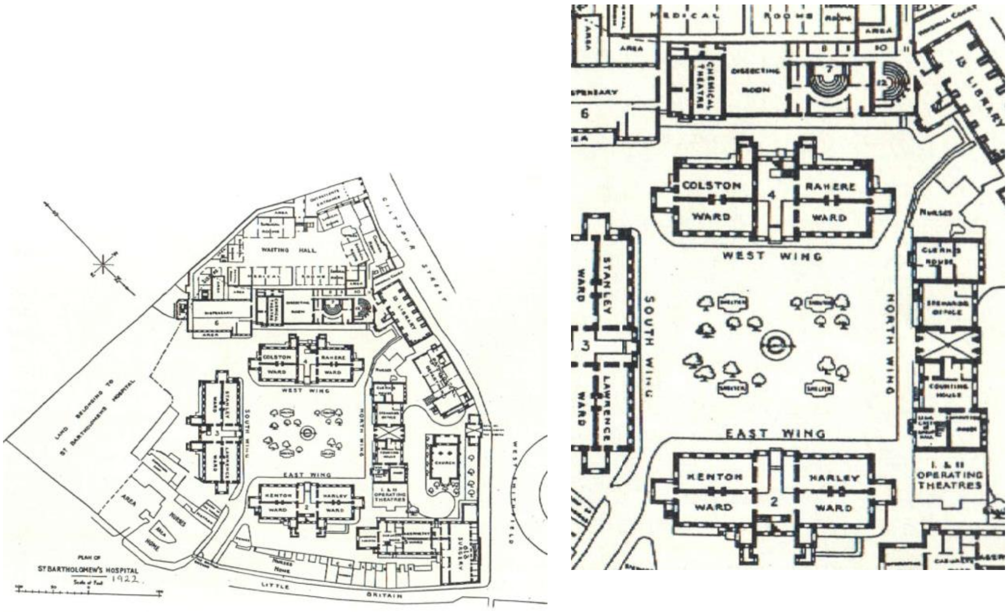
[1] Dimensions for equipment (Porter, 1996:153).
[2] Dimensions for Piorry stethoscope (1835) (Museum of Historical Medical Artifacts, 2012c).

5.1.4 Use of anaesthesia and sterilisation (post-1840s)

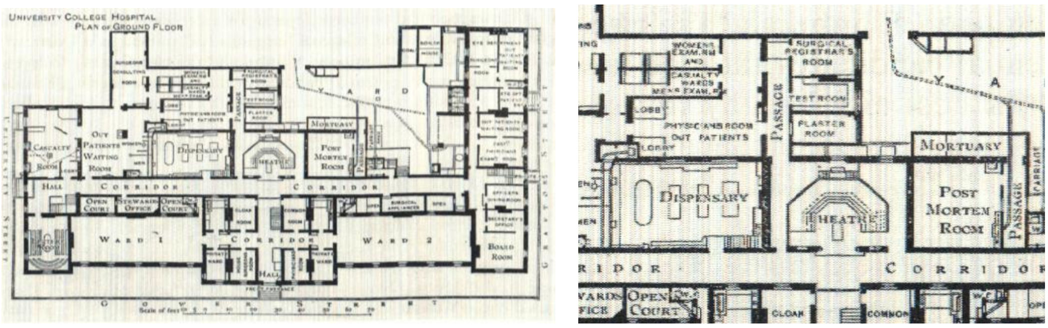
Anaesthetic Area: 0.0077sqm (0.1524m x 0.0508m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient on OT table	1.29	Person
27	Space for administrator	1.00	Person, Workspace
28	Space for administrator’s assistant x 4	3.20	Person, Workspace
34	Space for workstation	0.70	Workspace, Equipment
25	Space for numerous spectators x 10	12.00	Person
	Total/person	18.19	
	Equipment: Area ratio	1:2362	

Appendix E.20 Table of spatial analysis: Anaesthetic equipment.

5.1.5 Surgical investigations & new medical knowledge



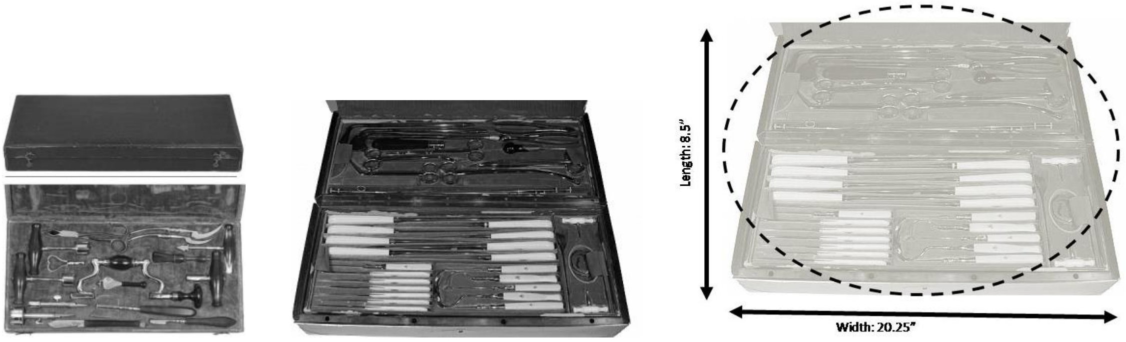
Appendix E.21 Plan of St. Bartholomew’s Hospital (Barry & Carruthers, 2005:54).



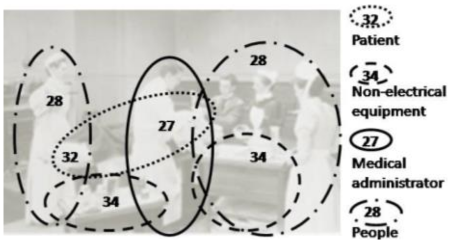
Appendix E.22 New OT on Ground Floor Plan, UCL (1841) (Barry & Carruthers, 2005:124).

5.1.5 Surgical investigations & new medical knowledge

Appendix E.23 Richardson. R (2008*) The Making of Mr. Gray's Anatomy Bodies, books, fortune, fame,* Oxford University Press.



Appendix E.24 Left: An early 19th century neurosurgical set. Signed by Zitier, Heine and Sandill. Size: (Approximate) 700 × 450 × 50 mm (Phisick Medical Antiques, 2013). **Middle & Right: Appendix E.24a** Spatial analysis of surgical set (Museum of Historical Medical Artifacts, 2012e).



Left: Appendix E.25 Operating room, 1896 at the Metropolitan Hospital, London (Wellcome Library, 1896). **Right: Appendix E.25a** Spatial analysis of Appendix E.25.

Surgical Equipment Area(Appendix E.24a): 0.111sqm (0.51435m x 0.2159m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient on OT table	1.29	Person
27	Space for administrator	1.00	Person, Workspace
28	Space for administrator’s assistant x 4	3.20	Person, Workspace
34	Space for workstation x 2	1.40	Workspace, Equipment
25	Space for numerous spectators x 10	12.00	Person
	Total/person	18.89	
	Equipment: Area ratio	1:62	

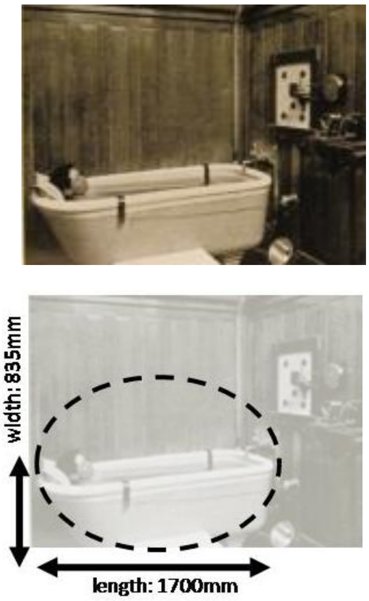
Appendix E.26 Table of spatial analysis: Surgical equipment.

5.1.6 Analysis of pre-electrical technology

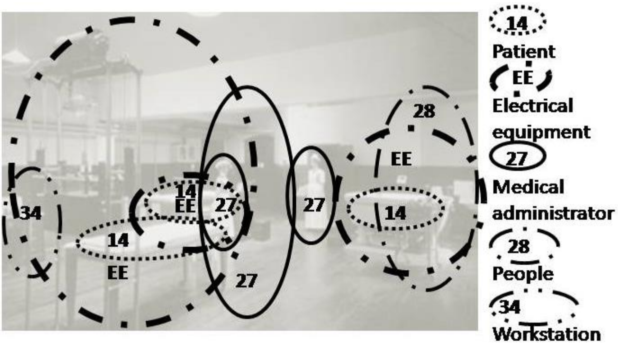
Sample No.	Equipment	Equip. Area (single)/sqm	Equipment Area (process)/sqm	Ratio Single:Process
1	Microscope	0.019	7.60	1:400
2	Vaccination	0.00108	4.28	1:3963
3	Stethoscope	0.0038	11.04	1:2905
4	Anaesthesia & sterilisation	0.0077	18.19	1:2362
5	Surgical	0.111	18.89	1:170
Total		**0.14258**	**62.41**	**1:438**
Average		**0.0285**	**12.482**	**1:438**

Appendix E.27 Tabled quantitative analysis of pre-electrical technological events.

5.2.1 Early-electrical years (1895-1950s) - (i) Electrotherapy



Left: Appendix E.28 *Electric Solenoid bath* (Monell, 1902) **Middle: Appendix E.28a** *Electrotherapeutic d'Arsonval cage by Richard Heller, Paris* (Science Museum, 2013). **Right: Appendix E.28b** Spatial analysis of Appendix E.28a.

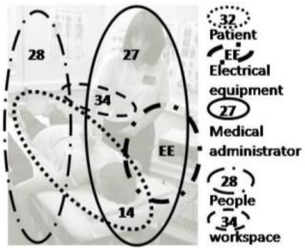


Left: Appendix E.28c The 1st Electrical Department, GOSH (HHARPa, 2010)
Right: Appendix E.28d Spatial analysis of Appendix E.28c.

5.2.1 Early-electrical years (1895-1950s) - (i) Electrotherapy

Galvanic Bath Area: 1.42sqm (1.7m x 0.835m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
14	Space for patient in bath	5.25	Person, Equipment
27	Space for administrator	1.00	Person, Workspace
28	Space for administrator’s assistant x 1	0.80	Person, Workspace
2 x Couch Equipment Area: 1.16sqm (1.68m x 0.69m)			
14	Space for patient lying on couch x 2	10.5	Person, Equipment
27	Space for administrator x 2	2.00	Person, Workspace
28	Space for administrator’s assistant x 2	1.60	Person, Workspace
34	Space for workstation	0.7	Workspace
	Total/person	21.85	21.85+1.42+2(1.16)=25.59
	All Equipment: Area ratio	1:6	

Appendix E.29 Table of spatial analysis: Electrotherapy equipment.



Left: Appendix E.30 Contemporary electrotherapy. **Right: Appendix E.30a** Spatial analysis of Appendix E.30.

Electrotherapy Equipment (2012) Area: 0.2209sqm (0.47m x 0.47m[3])			
	Spatial Functionality	**Area sqm**	**Functional area type**
14	Space for patient on couch (dual assist.)	5.25	Person
27	Space for administrator	1.00	Person, Workspace
28	Space for administrator’s assistant x 1	0.80	Person, Workspace
34	Space for workstation	0.70	Workspace, Equipment
	Total/person	7.75	
	Equipment: Area ratio	1:35	

Appendix E.31 Table of spatial analysis: Electro therapies equipment (individual).

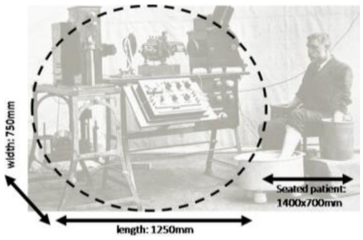
5.2.1 Early-electrical years - (i) Electrocardiograph (ECG)

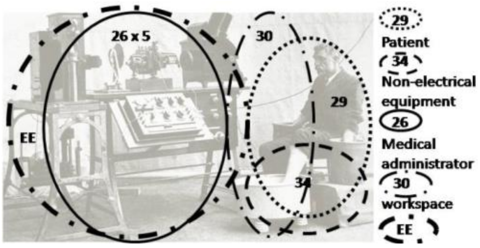
Left: Appendix E.32 Mobile ECG, c. 1920s (Smith, 2012). **Right: Appendix E.32a** Portable ECG, c. 1936 (Science Museum Archives).

---

[3] Dimensions based on EMS Physio manufacturer’s Megapulse Senior 265 shortwave unit model(470mm x 470mm x 940mm) [Online]. Available at: http://www.emsphysio.co.uk/11_megapulse-senior-265.htm (Accessed: 9th June 2012).

5.2.1 Early-electrical years - (i) Electrocardiograph (ECG)

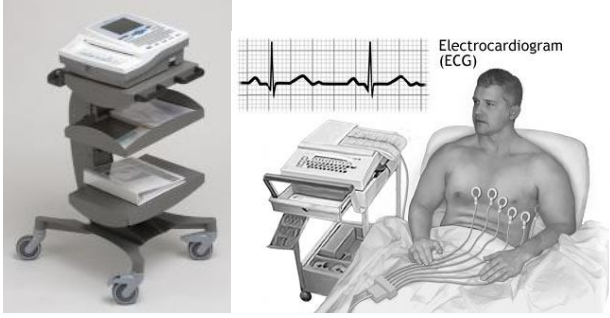


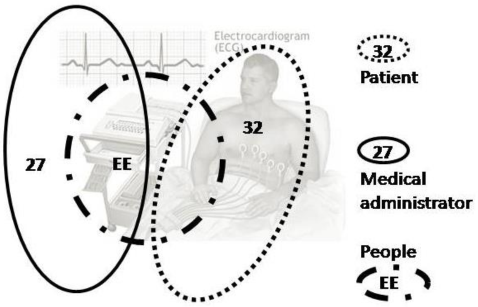


Left: Appendix E.33 Sir Thomas Lewis's ECG, University College Hospital Medical School (1912), Cambridge Scientific Instrument Company (1911) (Fisch, 2000:1742). This original ECG weighed 600lb and took 5 people to operate. Over time, it was reduced to an 8lbs one person operator ECG (Fisch, 2000:1740). As dimensions unavailable, approximations based on Appendix E.1, No.29 – Space for seated patient. **Right: Appendix E.33a** Spatial analysis of Appendix E.33.

ECG Equipment (1912) Area: 0.9375sqm (0.75m x 1.25m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
29	Space for seated patient	0.98	Person
30	Space for assistance beside chair	0.84	Workspace
26	Space for administrator x 5	5.00	Person, Workspace
34	Space for non-electrical equipment	0.70	Equipment
	Total/person	7.52	
	Equipment: Area ratio	1:8	

Appendix E.34 Table of spatial analysis: Electro therapies equipment.





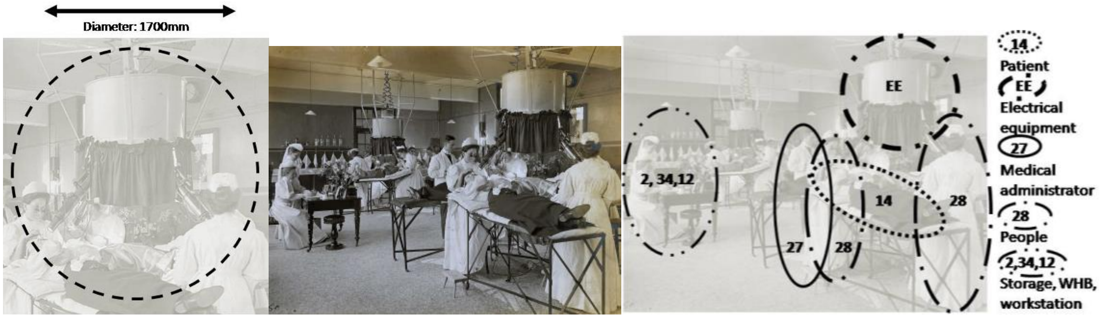
Left: Appendix E.35 2012, Burdick Atria 6100 ECG model (Cardiac Science, 2012).
Right: Appendix E.35a Spatial analysis of Appendix E.35.

ECG Equipment (2012) Area: 0.1702sqm (0.394m x 0.432m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
13	Space for patient on couch (single assist.)	4.34	Person
27	Space for administrator	1.00	Person, Workspace
26	Space for administrator's assistant	1.00	Person, Workspace
34	Space for workstation	0.70	Equipment
	Total/person	7.04	
	Equipment: Area ratio	1:41	

Appendix E.36 Table of spatial analysis: ECG equipment (individual).

5.2.1 Early-electrical years (1895-1950s) - (ii) Finsen Red Light Treatment (FRLT)

Appendix E.37 Left: *Lupus vulgaris Tuberculosis* (Brandel, 1872). **Mid-Right:** 1923, patient suffering with *bovine tuberculosis* (*Illustrated Medical Dictionary*, British Medical Association, 2002).



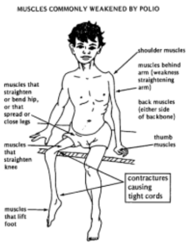
Left: Appendix E.38 Finsen red light treatment room, RLH (1900). **Right: Appendix E.38a** Spatial analysis of Appendix E.38.

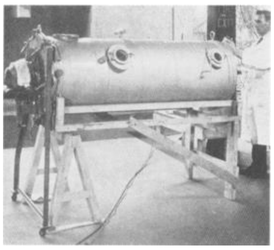
As the dimensions for FRLT equipment consist of 880mm minimum and 1700mm fully extended, the maximum dimension for the equipment's radius was employed in Appendix E.39 calculations (*Finsen ultraviolet lamp*, presented by Princess Alexandra to the London Hospital in 1900, Science Museum).

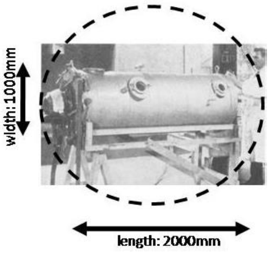
FRLT Equipment Area: 0.226sqm (0.3124m x 0.85m x 0.85m)			
3 x FRLT Equipment Area: 0.2631sqm			
	Spatial Functionality	**Area sqm**	**Functional area type**
14	Space for patient on couch (dual assist.)	5.25	Person
27	Space for administrator	1.00	Person, Workspace
28	Space for administrator's assistant x 2	1.60	Person, Workspace
34	Space for workstation	0.70	Workspace, Equipment
12	Space for wash hand basin (WHB)	1.08	Person
2	Space for storage x 2	4.60	Storage
	Total/workstation	14.23	
	Equipment: Area ratio	1:63	
	Total/workstation x 3	31.33	3(14+27+28+34)+12+2
	Equipment: Area ratio	1:139	

Appendix E.39 Table of spatial analysis: Electro therapies equipment (individual).

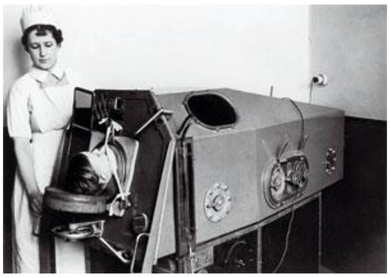
5.2.1 Early-electrical years (1895-1950s) - (iii) Drinker Respirator

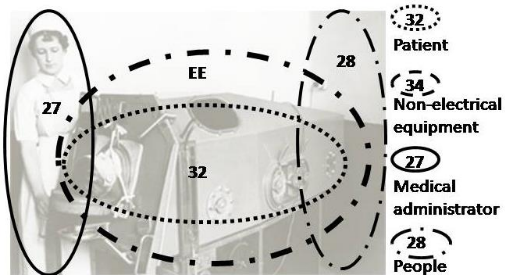




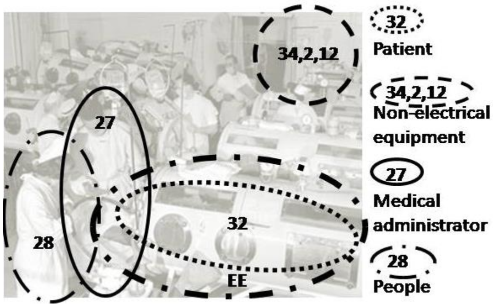


Left: Appendix E.40 *Poliomyelitis* patient**. Middle-Right: Appendix E.40a&b** Original cylindrical tank respirator with a 'patient' inside. Dimensions of Drinker respirator (Meyer, 1990:490).





Left: Appendix E.41 Single Drinker Respirator (GOSH). **Right: Appendix E.41a** Spatial analysis of Appendix E.41.

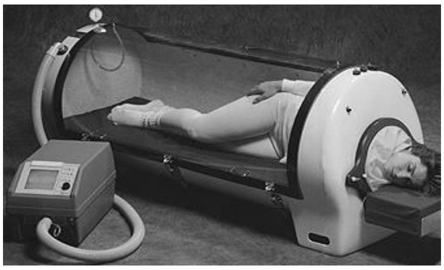


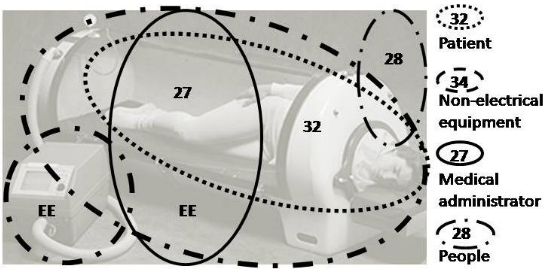
Left: Appendix E.42 Medical personnel tend to polio victims in an iron lung ward (1950s) at the Haynes Memorial Hospital, Boston (Meyer, 1990:491). **Right: Appendix E.42a** Spatial analysis of Appendix E.42.

Drink Respirator Equipment Area: 1.19sqm (1.7m x 0.7m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient in drinker equipment	1.19	Person
27	Space for administrator	1.00	Person, Equipment
28	Space for administrator's assistant x 1	0.80	Person
34	Space for workstation	0.70	Workspace, Equipment
2	Space for storage	2.30	Storage
12	Space for WHB	1.08	Hygiene
	Total/treated person	7.07	
	Equipment: Area ratio	1:6	
	Total/treated person x 7	29.21	7(32+27+28+34)+2+12
	Equipment: Area ratio x 7	1:3.5	

Appendix E.43 Table of spatial analysis: Electro therapies equipment (individual).

5.2.1 Early- electrical years (1895-1950s) - (iii) Drinker Respirator





Left: Appendix E.44 Treatment of patient in negative pressure mechanical ventilator (2000s). [Online]. Available at: http://www.wikidoc.org/index.php/File:Womanonsideinlung.jpg (Accessed: 20th December 2011). **Right: Appendix E.44a** Spatial analysis of Appendix E.44.

As dimensions for the above model seem to be unavailable, the dimensions for a similar *Hyperbaric Oxygen Chamber* apparatus were substituted for calculations in table Appendix E.45.

Mechanical Ventilator Equipment Area: 3.2875sqm (2.63m x 1.25m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient in lying position[4]	3.2875	Person
27	Space for administrator	1.00	Person, Workspace
28	Space for administrator’s assistant x 2	1.60	Person, Workspace
34	Space for workstation	0.70	Workspace, Equipment
2	Space for storage	2.30	Storage
12	Space for WHB	1.08	Hygiene
	Total/person	9.9675	
	Equipment: Area ratio	1:3	
	Total/person x 7	49.4925	7(32+27+28+34)+2+12
	Equipment: Area ratio x 7	1:1.5	

Appendix E.45 Table of spatial analysis: Mechanical Ventilator equipment (individual).

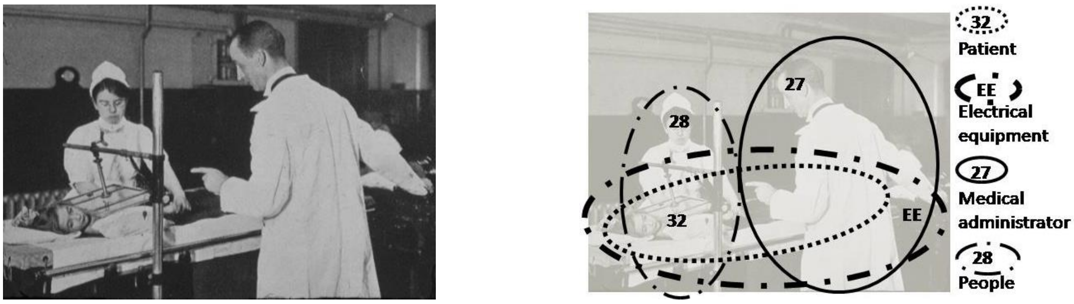
Sample No.	**Equipment**	**Equipment Area (single)/sqm**		**Equipment Area (process)/sqm**		**Ratio Single:Process**	
		1900s	**2000s**	**1900s**	**2000s**	**1900s**	**2000s**
6	Electro-therapy	1.42	0.9375	21.85	7.75	1:6	1:35
7	Electro (ECG)	0.9375	0.1702	7.52	7.04	1:8	1:41
8	FRLT	0.226	NE*	14.23	NE*	1:139	NE*
9	‘Iron Lung’	1.19	3.2875	29.21	49.493	1:3.5	1:1.5
Total		**3.77**	**4.3952**	**72.81**	**64.283**	**1:19**	**1:14.6**
Average		**0.9425**	**1.465**	**18.2**	**21.43**	**1:19**	**1:14.6**

Appendix E.46 Tabled quantitative analysis of early- electrical technological events. (NE*:non-existent).

---

[4] Dimensions from Sechrist Products, Hyperbaric Products, Sechrist 4100H model [Online]. Available at: http://www.sechristind.com/hyperbaric-chamber-4100H.html (Accessed: 12th June 2012).

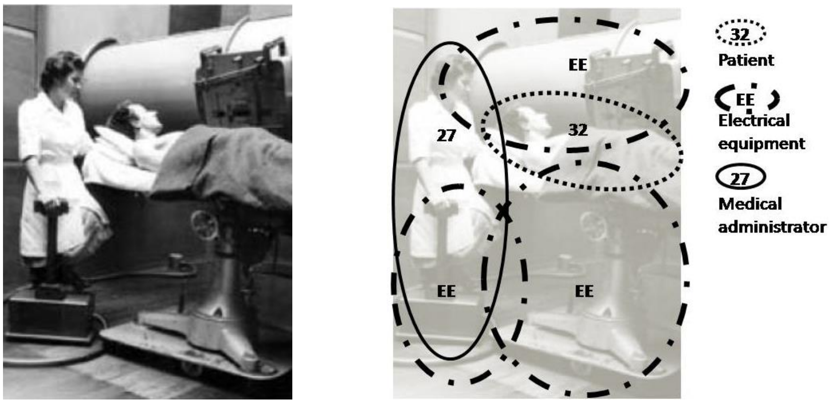
5.2.2 Development of Radiology Department



Appendix E.47 X-ray Department, GOSH, which first opened in 1902 (HHARPb, 2010). **Right: Appendix E.47a** Spatial analysis of Appendix E.47.

X-ray Equipment (1900s) Area: 1.08sqm (0.6858m x 1.5748m)[5]			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient lying on table	1.29	Person
27	Space for administrator	1.00	Person, Workspace
28	Space for administrator's assistant	2.40	Person, Workspace
	Total/person	4.69	
	Equipment: Area ratio	1:4	

Appendix E.48 Table of spatial analysis: X-ray equipment, 1900s (individual).



Left: Appendix E.49 1 million volt x-ray machine at The Barts (1950) (NHS Trust Archives, 2008:panel8). **Right: Appendix E.49a** Spatial analysis of Appendix E.49.

X-ray Equipment (1950s) Area: 2.16sqm (0.6858m x 1.5748m)+(power supply[6])			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient lying on table	1.29	Person
27	Space for administrator	1.00	Person, Workspace
	Total/person	2.29	
	Equipment: Area ratio	1:1	

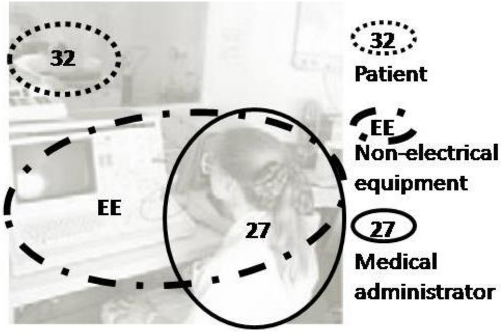
Appendix E.50 Table of spatial analysis: 1 million volt x-ray machine, 1950s (individual).

---

[5] Dimensions based upon Electrostatic X-Ray Machine (1905), 27" deep x 62" wide, manufactured by VanHouten and Tenbroeck [Online]. Available at: http://www.mohma.org/instruments/category/radiology /electrostatic x-ray machine / (Accessed: 8th June 2012).

[6] In proportion to patient size in figure AE.49, an approximation of equipment power size was assumed to be large than 1.08sqm. However, as this information is not available, the figure of 1.08sqm was used as a minimum spatial effect x-ray equipment in 1950s.

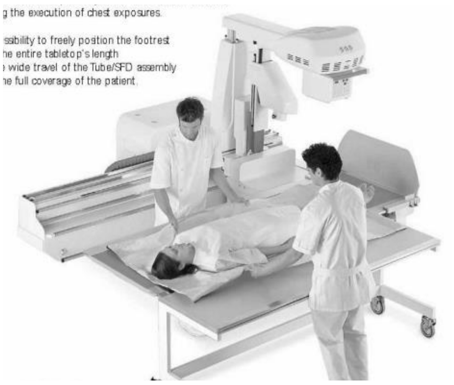
5.2.2 Development of Radiology Department

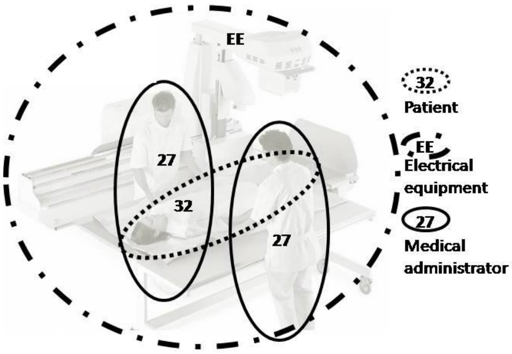


Left: Appendix E.51 Radiographer operates body scanner, RLH (1993) (NHS Trusts, 2008:panel11). **Right: Appendix E.51a** Spatial analysis of Appendix E.51.

X-ray Control Equipment Area: No.10 = Space for workstation, 5sqm			
	Spatial Functionality	**Area sqm**	**Functional area type**
27	Space for administrator	1.00	Person, Workspace
	Total/person	1.00	
	Equipment: Area ratio	1:0.2	

Appendix E.52 Table of spatial analysis: X-ray control room equipment (individual).





Left: Appendix E.53 Plain film x-ray[7] (Clisis, 2013).
Right: Appendix E.53a Spatial analysis of Appendix E.53.

Plain x-ray (2010s) Area: 8.238sqm (3.48m x 1.85m)+(2.4m x 0.75m) [8]			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient lying on table	1.29	Person
27	Space for administrator x 2	2.00	Person, Workspace
34	Space for workstation	0.70	Workspace, Equipment
	Total/person	3.99	
	Equipment: Area ratio	1:0.5	

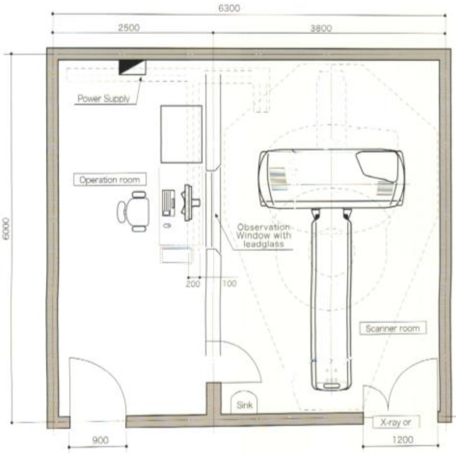
Appendix E.54 Table of spatial analysis: Plain x-ray equipment, 2010s (individual).

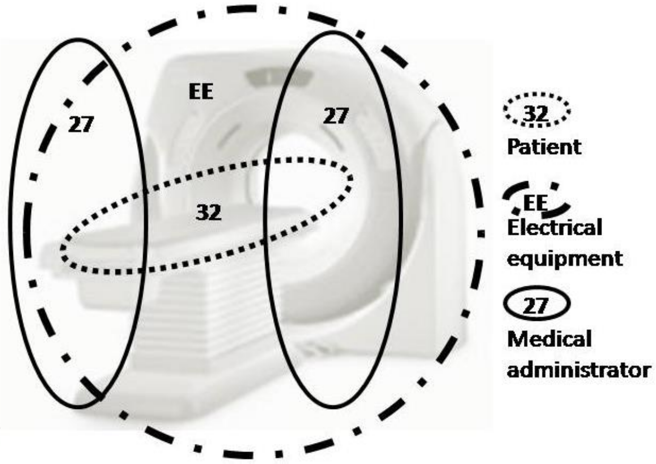
---

[7] Dimensions based on Clisis R&F system model. Available at: http://www.rslmedical.ie/X-RAY.html (Accessed: 14th June 2012).

[8] Dimensions based on equipment movement range for Moveable vertical stand VM and table dimensions, Philips range.

5.2.2 Development of Radiology Department

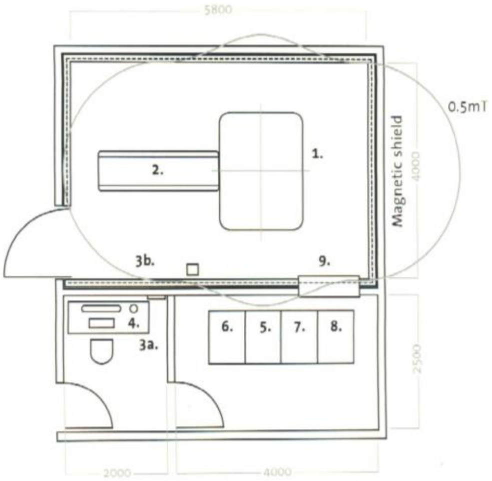


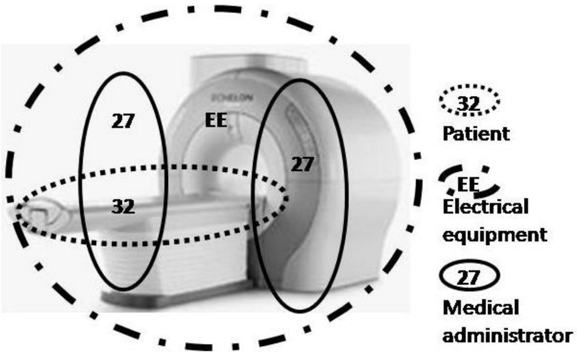


Left: Appendix E.55 CT scanner[9] (Hitachi, 2012).
Right: Appendix E.55a Spatial analysis of Appendix E.55.

CT Equipment Area: 4.199sqm (2.9m x 0.75m)+(0.88m x 2.3m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient lying on table	1.29	Person, Equipment
27	Space for administrator x 2	2.00	Person, Workspace
	Total/person	3.39	
	Equipment: Area ratio	1:0.8	

Appendix E.55b Table of spatial analysis: CT equipment 2010s.





Left: Appendix E.56 MRI scanner[10] (Hitachi, 2012).
Right: Appendix E.56a Spatial analysis of Appendix E.56.

---

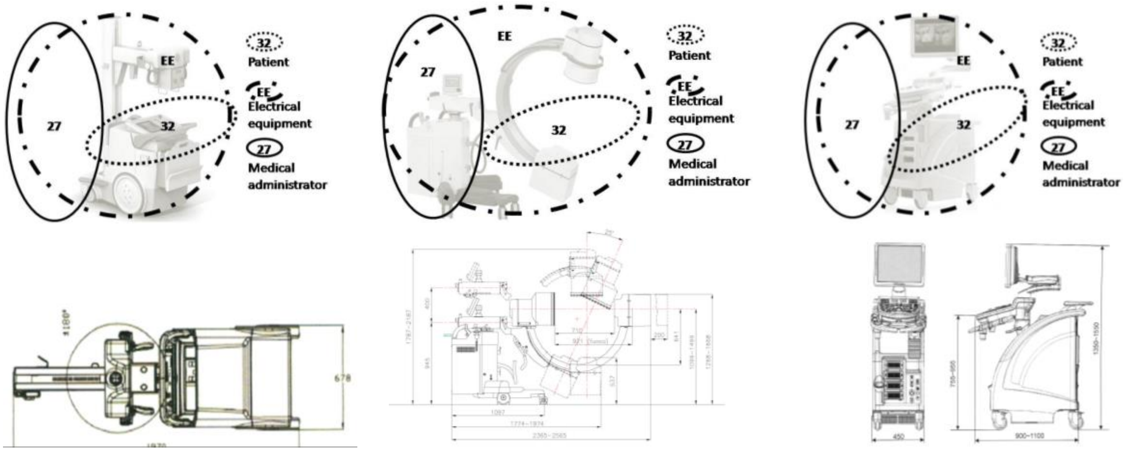
[9] Image and dimensions based on Hitachi's Scenaria 64-ch multi-slice CT. Available at: http://www.hitachi-medical-systems.eu/products-and-services/ct/scenaria.html (Accessed: 14th June 2012).

[10] Image and dimensions based on Hitachi's Scenaria 64-ch multi-slice CT. Available at: http://www.hitachi-medical-systems.eu/products-and-services/mri/echelon-15t.html (Accessed: 14th June 2012).

5.2.2 Development of Radiology Department

MRI Equipment Area: 5.005sqm (1.6m x 2.1.m)+(2.35m x 0.7m)			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient lying on OT	1.29	Person
27	Space for administrator x 2	2.00	Person, Workspace
	Total/person	3.29	
	Equipment: Area ratio	1:0.7	

Appendix E.56b Table of spatial analysis: MRI equipment 2010s.



Left to Right : Appendix E.57 Mobile equipment and spatial analyses[11].

Mobile X-ray Equipment Area: 1.336sqm (1.97m x 0.678m) **Mobile CT Equipment Area: 5.63sqm (2.529m x 2.2275m)** **Mobile US Equipment Area: 0.495sqm (0.45m x 1.1m)**			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient on OT table	1.29	Person
27	Space for administrator	1.00	Person, Workspace
	Total/person	2.29	
	Mobile X-ray Equipment: Area ratio	1:2	
	Mobile CT Equipment: Area ratio	1:0.4	
	Mobile US Equipment: Area ratio	1:5	

Appendix E.58 Table of spatial analysis: Mobile radiological equipment.

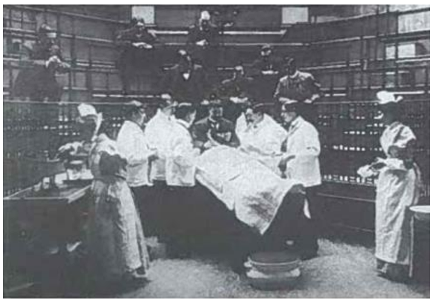
5.2.3 20th century surgical innovation

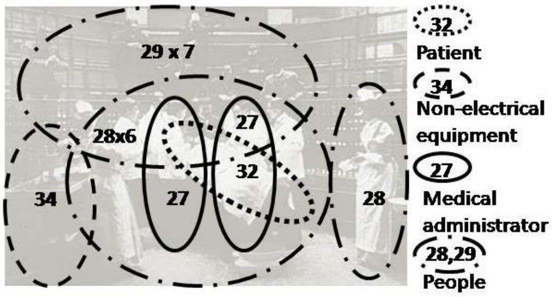
Appendix E.59 Bi-plane angio/Integrated OR – South West Washington medical Centre, WA, NBBJ architects.

---

[11] All dimensions and equipment sourced from RSL Medical. Available at: http://www.rslmedical.ie/index.html (Accessed: 14th June 2012).

5.2.3 20th century surgical innovation

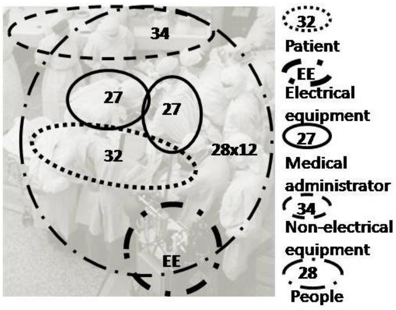




Left: Appendix E.60 An operation in progress, UCH, 1898 (Barry & Carruthers, 2005:126). **Right: Appendix E.60a** Spatial analysis of Appendix E.60.

Surgical Equipment Area: 0.111sqm (see AE.25)			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient on OT table	1.29	Person
27	Space for administrator x 2	2.00	Person, Workspace
28	Space for administrator’s assistant x 7	5.60	Person, Workspace
29	Space for seated persons x 7	6.86	Person
34	Space for workstation	0.70	Workspace, Equipment
	Total/person	16.45	
	Equipment: Area ratio	1:148	

Left: Appendix E.61 Table of spatial analysis: Surgical equipment 1898.
Right: Appendix E.61a Spatial analysis of Appendix E.61.



Left: Appendix E.62 OT room, RLU (1920) (Royal London Hospital Archives).
Right:Appendix E.62a Spatial analysis of Appendix E.62.

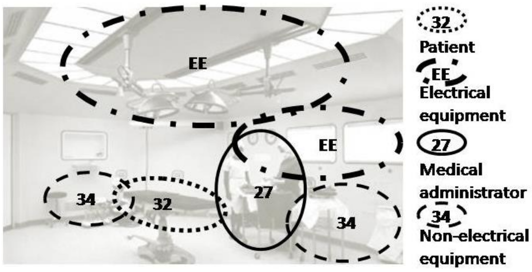
Surgical Equipment Area: 1.233sqm (1.37m x 0.9m)[12]			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient on OT table	1.29	Person
27	Space for administrator x 2	2.00	Person, Workspace
28	Space for administrator’s assistant x 12	9.6	Person, Workspace
34	Space for workstation x 2	1.40	Workspace, Equipment
	Total/person	14.29	
	Equipment: Area ratio	1:12	

Appendix E.63 Table of spatial analysis: Surgical equipment 1920.

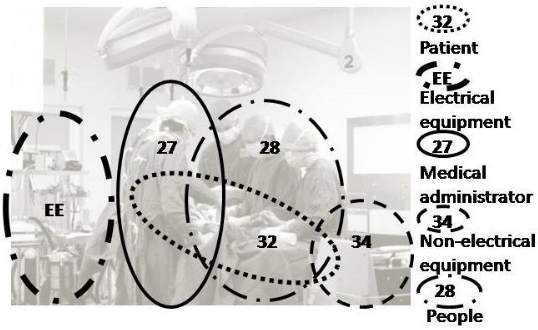
---

[12] Dimensions for anaesthetic machine: H (254mm) x W(90mm) x D(137mm) (Science Museum, London).

5.2.3 20th century surgical innovation



Left: Appendix E.64 OT room, Mile End Hospital, 1971 (NHS Trusts, 2008:Panel10). **Right: Appendix E.64a** Spatial analysis of Appendix E.64.



Appendix E.65 Operation in progress, RLH (1993) (NHS Trusts, 2008:Panel11). **Right: Appendix E.65a** Spatial analysis of Appendix E.65.

Surgical Equipment Area: 2.28sqm (1.5m x 0.6m) + (0.69sqm x 2)[13]			
	Spatial Functionality	**Area sqm**	**Functional area type**
32	Space for patient on OT table	1.29	Person
27	Space for administrator	1.00	Person, Workspace
28	Space for administrator’s assistant x 3	2.40	Person, Workspace
34	Space for workstation	0.70	Workspace, Equipment
	Total/person	5.39	
	Equipment: Area ratio	1:2.4	

Appendix E.66 Table of spatial analysis: Surgical equipment for small OT room in 1970-90s.

5.2.3 20th century surgical innovation

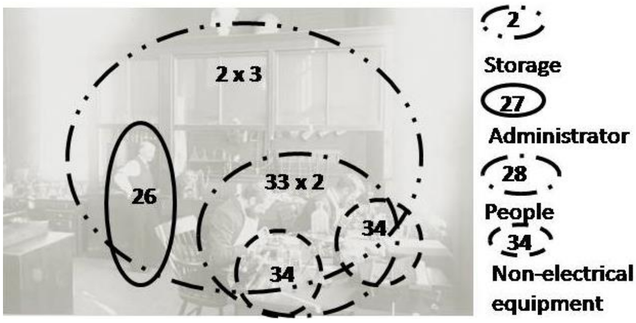
As per current HBN guidance, dimensions assigned to technology (and movement) are 1600mm zone around the patient table. This calculates as 2.1186mm x 3.5631mm = 7.548sqm allocated within a 55sqm OT room.

Appendix E.67 HBN calculations of area for technology in OT room (HBN26&28)

---

[13] Centanaest ventilator/ anaesthetic apparatus, (1950-1970) and gas cylinders, British Oxygen Company Limited manufacturers (Science Museum).

5.2.4 Laboratory Revolutions



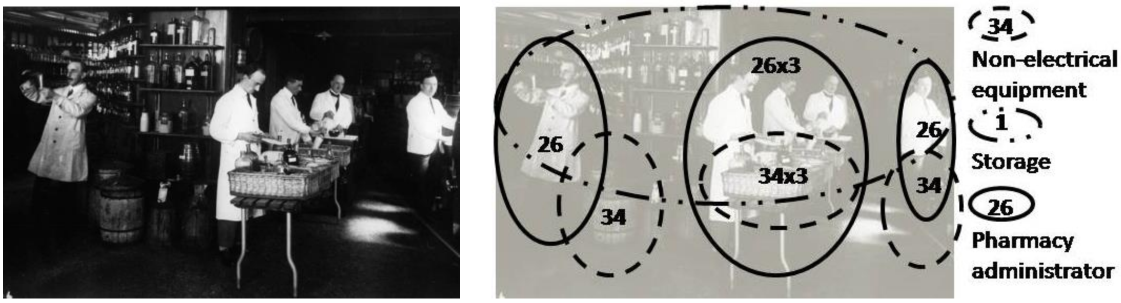
Left: Appendix E.68 William Fiske Whitney and Francis Dexter in the Anatomy Laboratory at Boylston Street, circa 1900. Gift of Mrs. Lyman Whitney to the Harvard Medical Library, 1961 (Centre for the History of Medicine, 2013).
Right: Appendix E.68a Spatial analysis of Appendix E.68.

Pathology Equipment Area: 0.019sqm (see AE.10)			
Spatial Functionality		**Area sqm**	**Functional area type**
26	Space for standing person	1.00	Person
33	Space for sitting at workstation x 2	1.8	Person
34	Space for workspace adjacent to equipment x 2	1.4	Workspace, Equipment
2	Space for storage full height x 3	6.9	Storage
	Total/piece of equipment	11.1	
	Equipment: Area ratio	1:584	

Appendix E.69 Table of spatial analysis: Pathology equipment.

Left: Appendix E.70 DNA sequencing machine (ABC News, 2011).
Right: Appendix E.70a Opti R Blood gas and electrolyte analyzer, example of a NPT machine (Aris Mantzoros S.A., 2012)

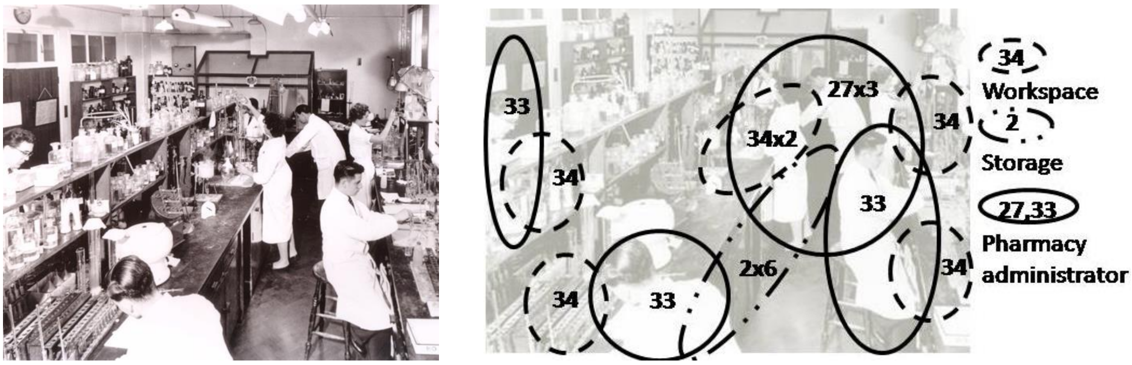
5.2.4 Laboratory Revolutions



Left: Appendix E.71 A scene from the hospital's pharmacy c.1906 (GOSH) (HHARPb, 2010). **Right: Appendix E.71a** Spatial analysis of Appendix E.71.

Pharmaceutical Equipment Area: 0.00sqm (none shown)			
	Spatial Functionality	**Area sqm**	**Functional area type**
26	Space for administrator x 5	5.00	Person, Workspace
34	Space for workstation x 5	3.50	Workspace, Equipment
1	Space for storage (high level) x 4	8.00	Storage
	Total/person	16.5	
	Equipment: Area ratio	-	

Appendix E.72 Table of spatial analysis: Pharmaceutical equipment.

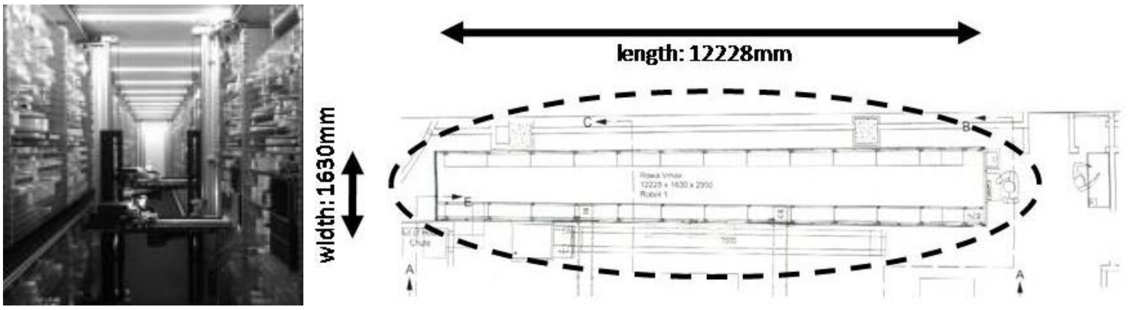


Left: Appendix E.73 *Birmingham Hospital Pharmacy* (University Hospitals Birmingham, 2011). **Right: Appendix E.73a** Spatial analysis of Appendix E.73.

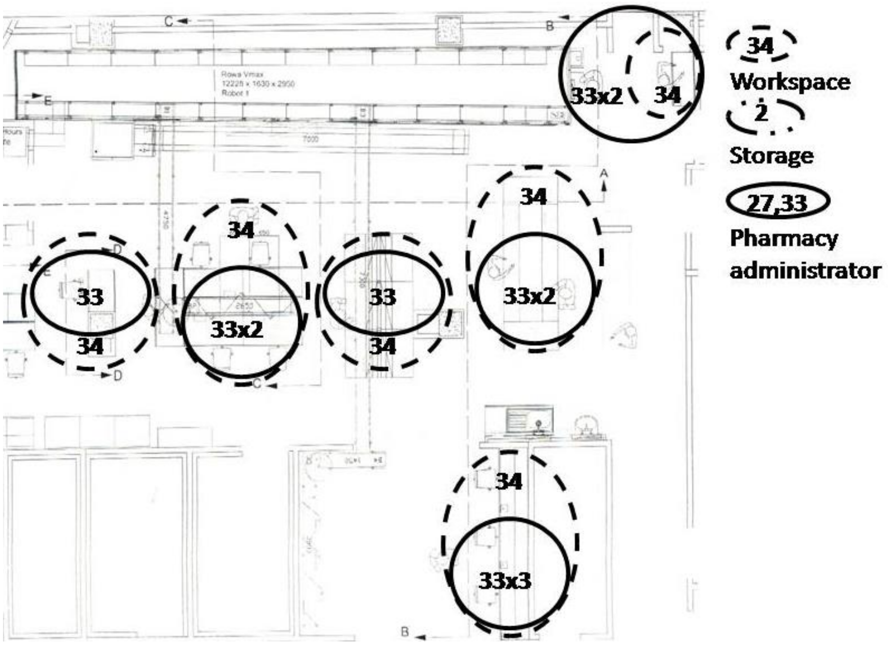
Pharmaceutical Equipment Area: 0.00sqm (none shown)			
	Spatial Functionality	**Area sqm**	**Functional area type**
27	Space for administrator x 3	3.00	Person, Workspace
33	Space for administrator x 3	2.70	Person, Workspace
34	Space for workstation x 6	4.20	Workspace, Equipment
2	Space for storage (low level) x 6	13.8	Storage
	Total/person	23.7	
	Equipment: Area ratio	-	

Appendix E.74 Table of spatial analysis: Pharmaceutical equipment.

5.2.4 Laboratory Revolutions



Left: Appendix E.75 Vmax Duplo Pharmacy robot by ARX (Luton and Dunstable Hospital). **Right: Appendix E.75a** Dimensions for Pharmacy robot ‘Doris’ at Pembury Hospital, Kent (Author’s own, Pembury Hospital, 2012).



Appendix E.76 Spatial analysis of Pembury Hospital pharmacy robot.

Pharmaceutical Equipment Area: 19.93sqm (12.228sqm x 1.630sqm)			
	Spatial Functionality	**Area sqm**	**Functional area type**
33	Space for administrator x 10	9.0	Person
34	Space for workstation x 9	6.3	Workspace, Equipment
	Total/person	15.3	
	Equipment: Area ratio	1:0.77	

Appendix E.77 Table of spatial analysis: Pharmacy robot, 2010.

Average	**Pre-electrical technology**
Equipment area	**0.0285sqm**
Functional area	**12.482sqm**
Ratio	**1:438**

Appendix E.79 Tabled quantitative analysis of pre-electrical technology events.

5.2.6 Analysis of post-electrical technology

Sample No.	Equipment	Equipment Area (single)/sqm		Equipment Area (process)/sqm		Ratio Single:Process	
		1900s	2000s	1900s	2000s	1900s	2000s
10-12	Imaging: X-ray	1.08	8.238	4.69	3.99	1:4	1:0.5
	Imaging CT	N/E*	4.199	N/E*	3.39	N/E*	1:0.8
	Imaging MRI	N/E*	5.005	N/E*	3.29	N/E*	1:0.7
	Imaging: Mobile X-ray	N/E*	1.336	N/E*	2.29	N/E*	1:2
	Imaging: Mobile CT	N/E*	5.63	N/E*	2.29	N/E*	1:0.4
	Imaging: Mobile US	N/E*	0.495	N/E*	2.29	N/E*	1:5
13	Surgery	0.111	16.45	2.28	5.39	1:148	1:2.4
14	Pathology	0.019	N/A	11.1	N/A	1:584	N/A
15	Pharmacy	N/A	19.93	N/A	15.3	N/A	1:0.8
Total		**1.21**	**61.283**	**18.07**	**38.23**	**1:15**	**1:0.6**
Average		**0.4**	**7.66**	**6.02**	**4.78**	**1:15**	**1:0.6**

Appendix E.78 Tabled quantitative analysis of post- electrical technology events. (NE*:non-existent, N/A : information not available).

Average	Early-electrical technology	
	1895	2000
Equipment area	0.9425sqm	1.465sqm
Functional area	18.2sqm	21.43sqm
Ratio	1 :19	1 :14.6

Appendix E.80 Tabled quantitative analysis of early-electrical technology events.

Average	Post-electrical technology	
	1895	2000
Equipment area	0.4sqm	5.9sqm
Functional area	6.02sqm	3.28sqm
Ratio	1 :15	1 :0.6

Appendix E.81 Tabled quantitative analysis of post-electrical technology events.

Technology type	Medical equipment area (single)	
Pre-electrical	0.0285sqm	
Early-electrical	0.9425sqm (1895)	1.465sqm (2000)
Post-electrical	0.4sqm (1895)	5.9sqm (2000)

Appendix E.82 Tabled analysis of medical equipment area (pre-post electrical).

5.2.6 Analysis of post-electrical technology

Technology type	Medical equipment functional area (process)	
Pre-electrical	12.482sqm	
Early-electrical	18.2sqm (1895)	21.43sqm (2000)
Post-electrical	6.02sqm (1895)	3.28sqm (2000)

Appendix E.83 Tabled analysis of medical equipment functional area (pre-post electrical).

Technology type	Total area (sqm)	
Pre-electrical	0.0285 + 12.482 = 12.5105	
Early-electrical	0.9425 + 18.2 = 19.1425	1.465 + 21.43 = 22.895
Post-electrical	0.4 + 6.02 = 6.42	5.9 + 3.28 = 9.18

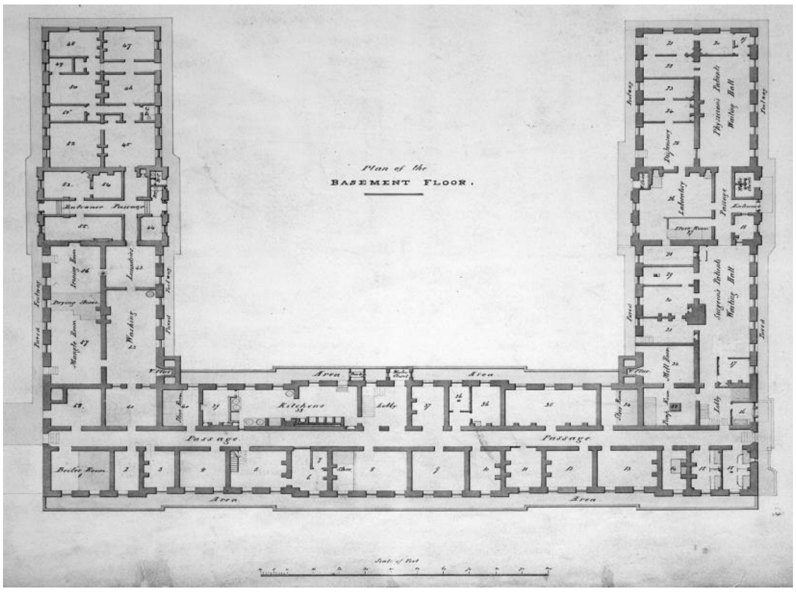
Appendix E.84 Tabled analysis of medical equipment functional area (pre-post electrical).

Technology type	% Medical equipment area: Total area	
Pre-electrical	0.228	
Early-electrical	4.9	6.4
Post-electrical	6	64.3

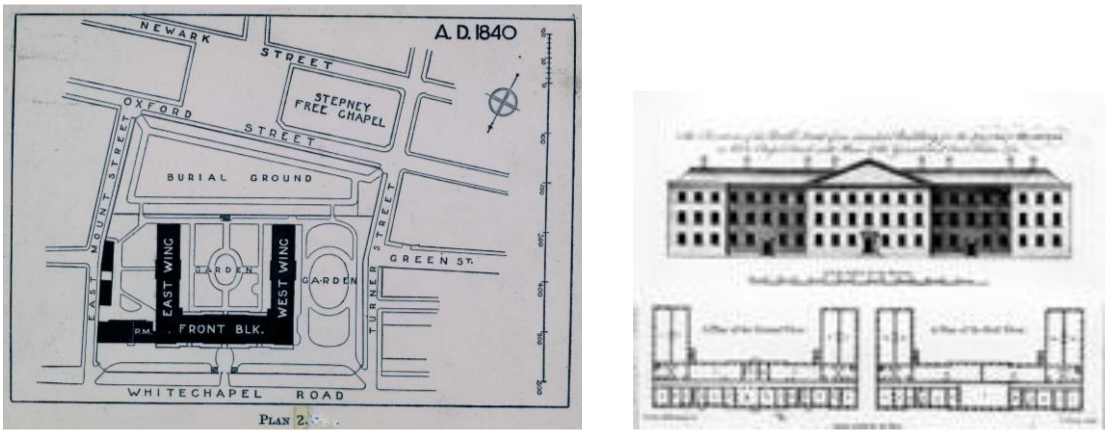
Appendix E.85 Tabled analysis of medical equipment area: functional area ratios (pre-post electrical).

Appendix F

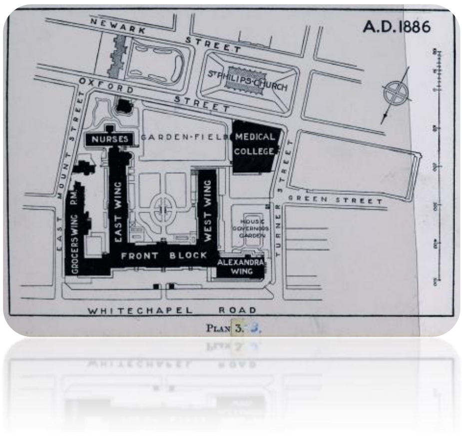
Case Study No.1: The RLH



Appendix F.1 1832, Basement Floor Plan (The Royal London Archive department).

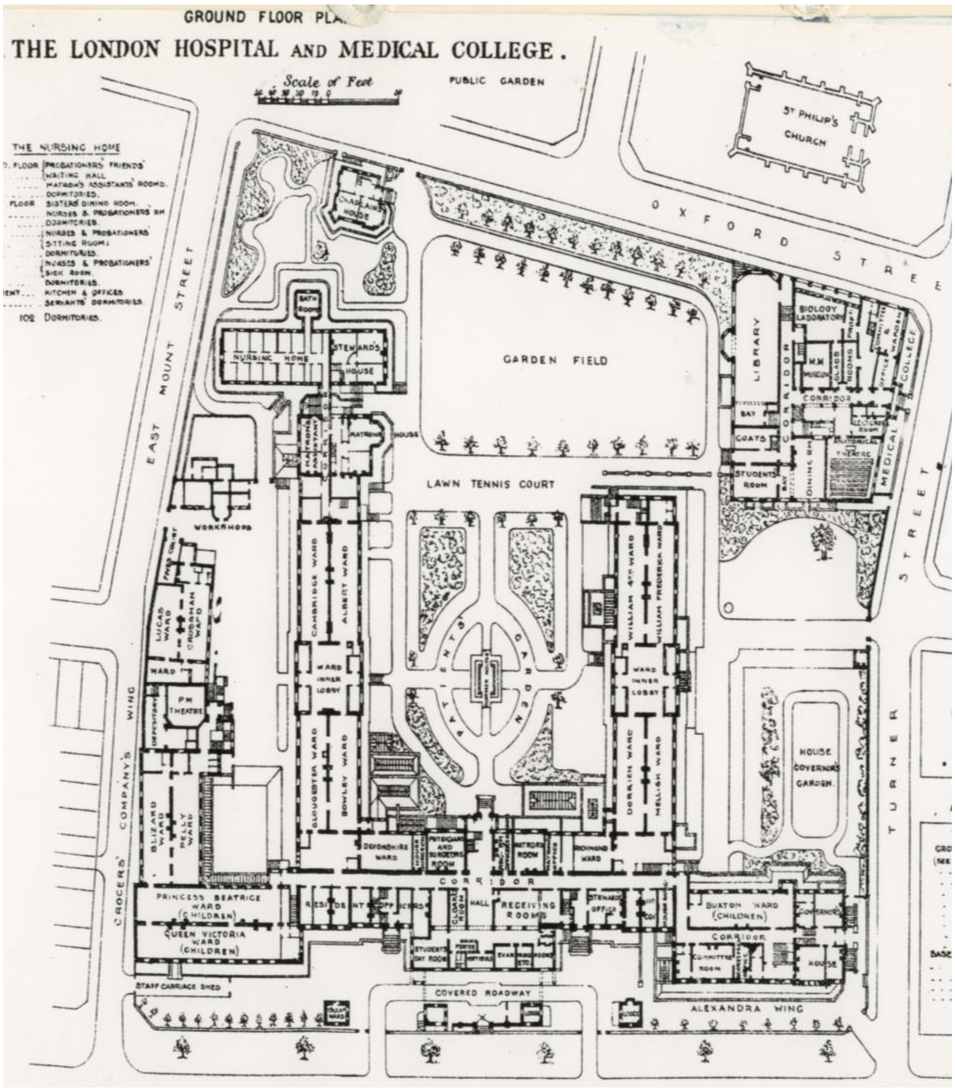


Appendix F.2 1840, Site block plan (The Royal London Archive department).

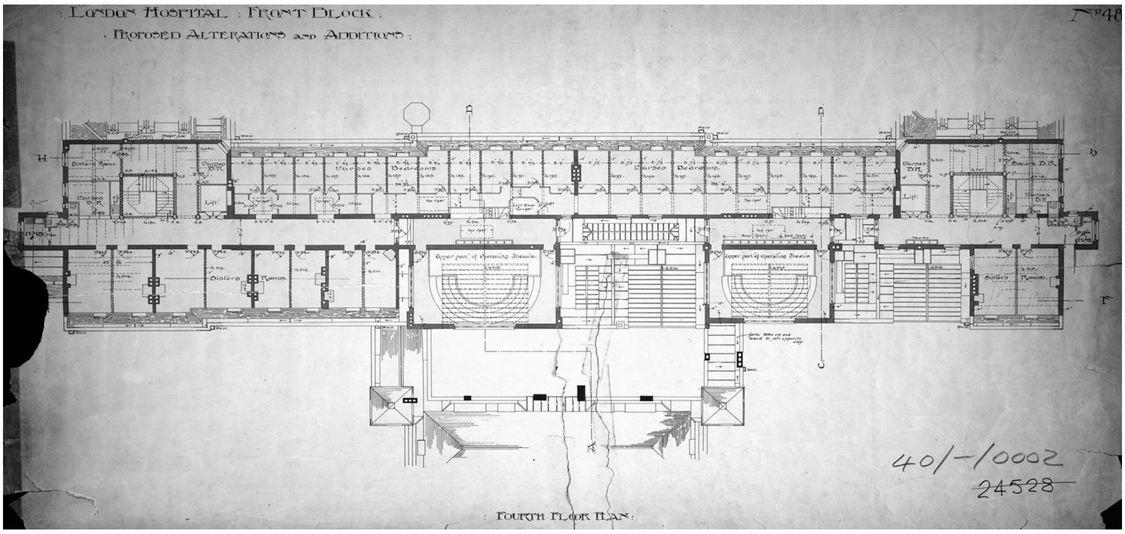


Appendix F.3 1886, The Medical College had been moved to its present location in the southwest corner of the grounds. The Alexandra wing and the Grocer’s wing had both been built, and at the end of the east wing the first nurses’ home was built (The Royal London Archive department).

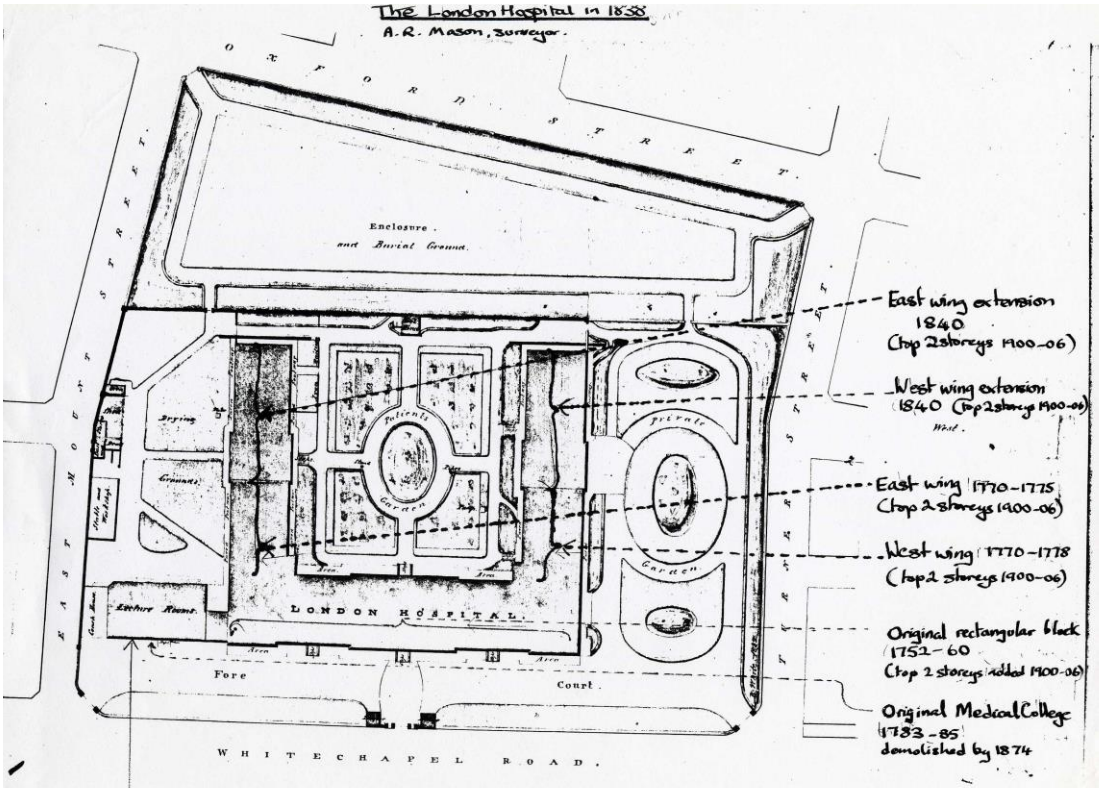
6.2 Case Study No.1: The RLH



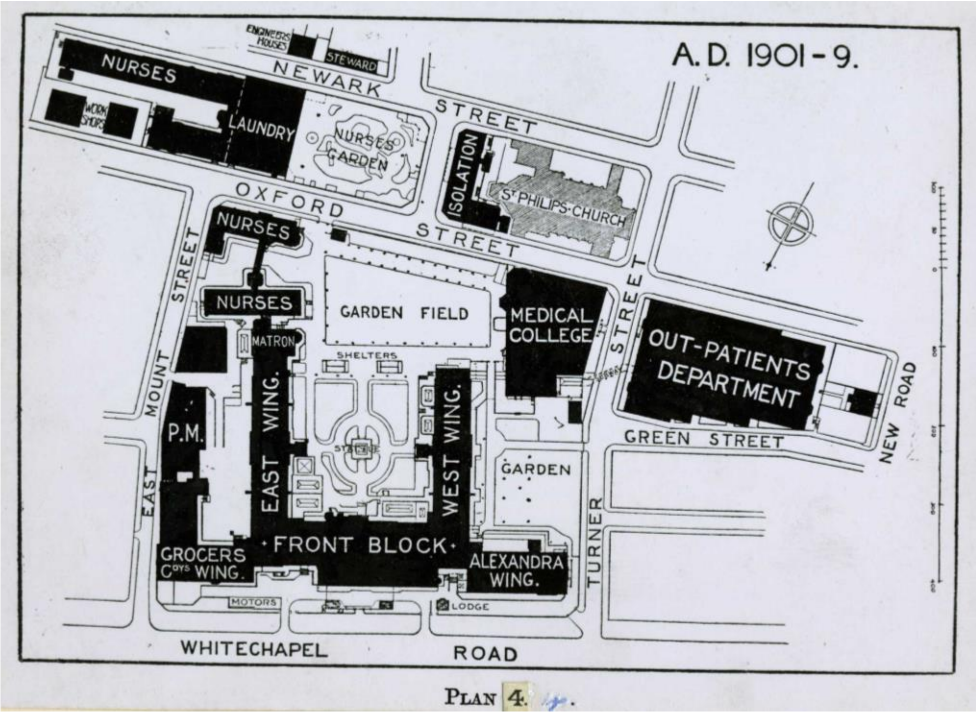
Appendix F.4 1886, Ground Floor Plan, The Royal London Hospital and Medical Centre (The Royal London Archive department).



Appendix F.5 1900, Fourth Floor Plan, Front Block, The London Hospital. (The Royal London Archive department).

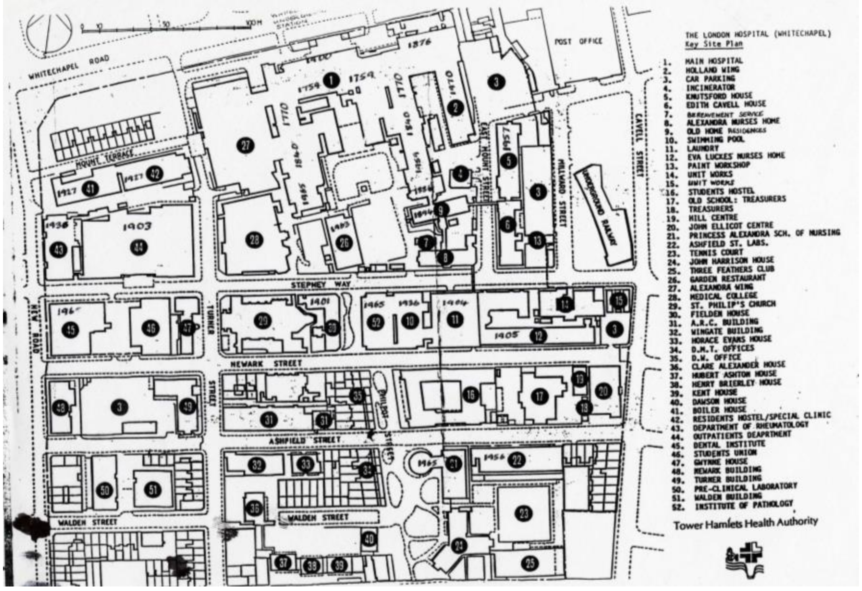


Appendix F.6 1900, Fourth Floor Plan, Front Block, The London Hospital. Masterplan highlighting the historical development of the hospital's buildings. (The Royal London Archive department).

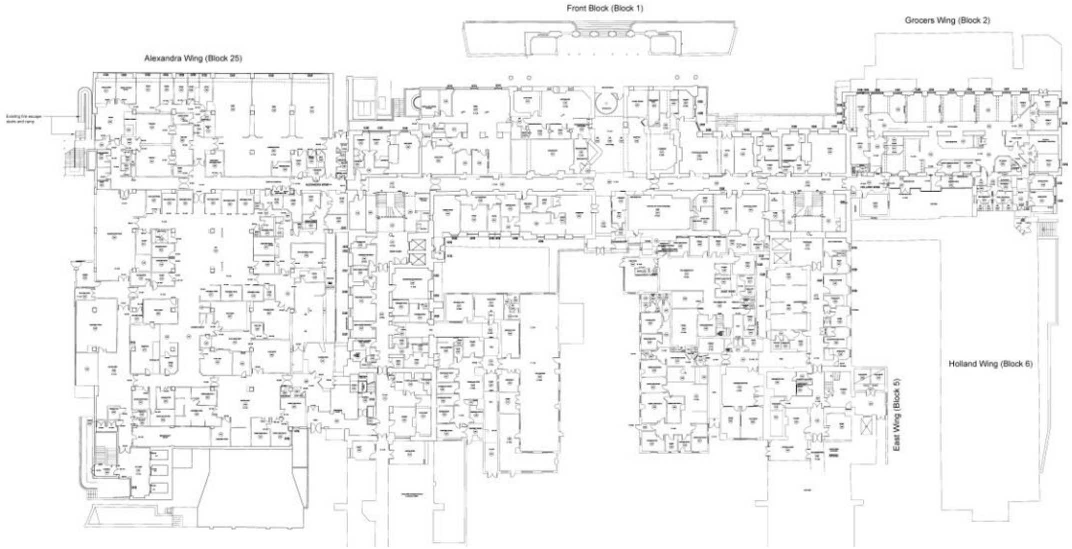


Appendix F.7 1900, Masterplan, The London Hospital complex. (The Royal London Archive department).

6.2 Case Study No.1: The RLH



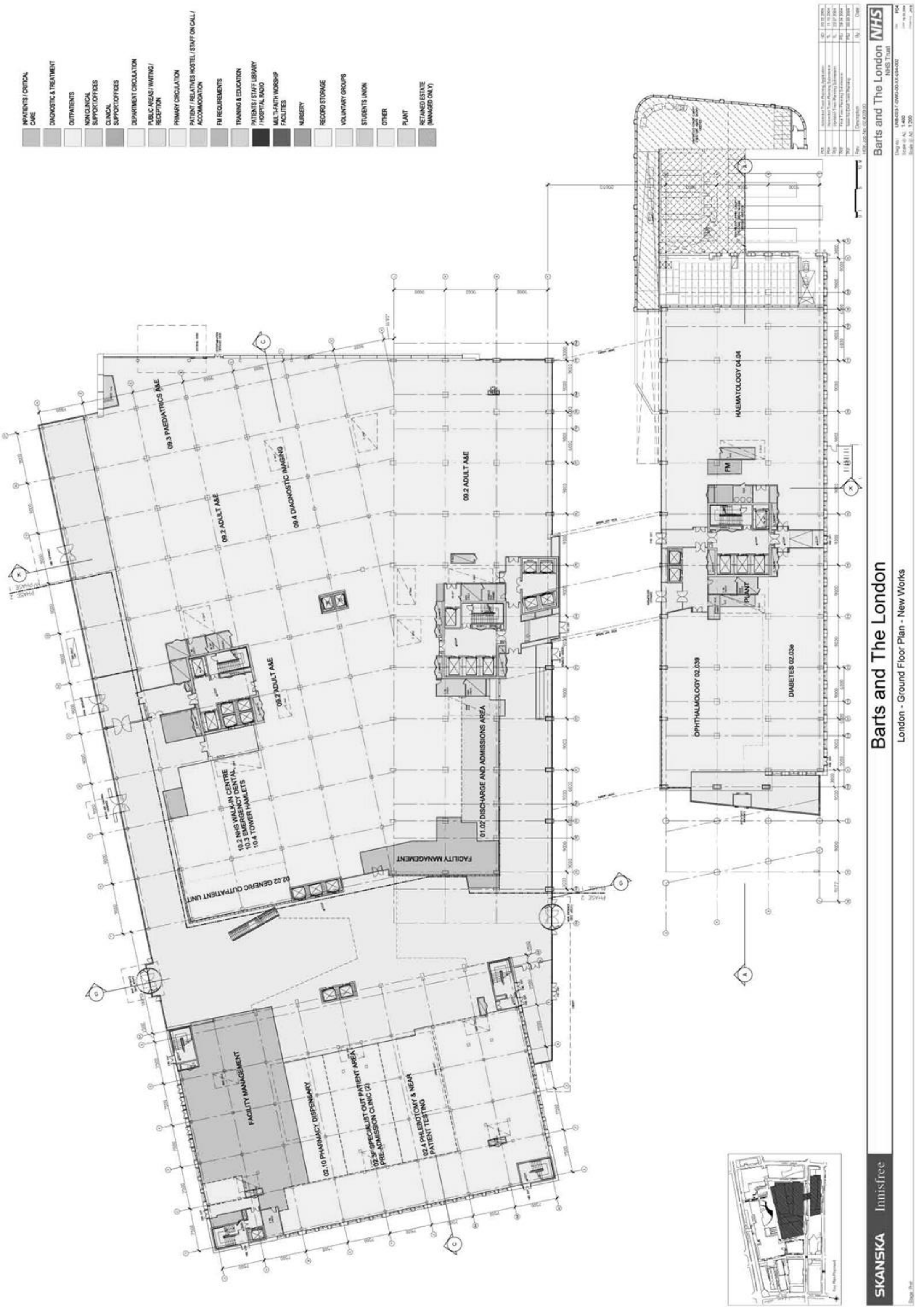
Appendix F.8 1950, Plan of campus development (The Royal London Archive department).



Appendix F.9 1950/2000, Excerpt of Ground Floor Plan, 1:200 drawing, internal planning.

Appendix F.10 Perspective view of new London Hospital (2012), HOK Architects.

6.2.2 The RLH: Analysis of measured plans



Appendix F.11 2012, Departmental Ground Floor Plan. The London Hospital, HOK Architects (1:500).

6.2.2 The RLH: Analysis of measured plans

Case Study No.1: The London Hospital 1832										
	Basement floor	Ground floor	First floor	Second floor	Third floor	Fourth floor	Fifth floor	Sixth floor	Total area/sqm	
Original Building										
Wards		2252.432	2342.9	2343.04					6938.372	55.1%
OPD	624.6								624.6	5.0%
Pathology	59.5								59.5	0.5%
Pharmacy	160								160	1.3%
Theatres				49					49	0.4%
Support	1946.37	633.5	667.1	441.7					3688.67	29.3%
Plant	95.79	0							95.79	0.8%
Comms	304.2	304.2	182.91	182.91					974.22	7.7%
Total area/sqm	3190.46	3190.132	3192.91	3016.65	0				12590.152	
Wards,OPD, support	2570.97	2885.932	3010	2784.74	950.88				12202.522	90.1%
									0	0.0%
High tech	219.5	0	0	49	0				268.5	2.0%
									0	0.0%
Plant/Comms.	399.99	304.2	182.91	182.91	0				1070.01	7.9%
Total area/sqm									13541.032	
Total area/sqm ex. Plant/Comms.									12471.022	
Wards,OPD, support									12202.522	97.8%
High tech									268.5	2.2%

Appendix F.12 1832, Tabled results from measured drawings.

Case Study No.1: The London Hospital 1886										
	Basement floor	Ground floor	First floor	Second floor	Third floor	Fourth floor	Fifth floor	Sixth floor	Total area/sqm	% of Total
Original Building										
Wards		2252.432	2342.9	2343.04					6938.372	48.4%
OPD	624.6								624.6	4.4%
Pathology	59.5								59.5	0.4%
Pharmacy	160								160	1.1%
Theatres				49					49	0.3%
Support	1946.37	633.5	667.1	441.7	950.88				4639.55	32.4%
Plant	95.79	0							95.79	0.7%
Comms	502.93	502.93	381.64	381.64					1769.14	12.3%
Total/sqm	3389.19	3388.862	3391.64	3215.38	950.88				14335.952	
East Wing										
Wards		542.64							542.64	
Support										
Plant										
Comms										
Total/sqm		542.64							542.64	
Alexander Wing										
Wards		156.13	497.43	497.43					1150.99	51.0%
Support		341.3			208.5				549.8	24.4%
Plant									0	
Comms		161.36	161.36	161.36	71.4				555.48	24.6%
Total/sqm		658.79	658.79	658.79	279.9				2256.27	
Grocer's Wing										
Pathology		240.3							240.3	5.8%
Wards		1027.9	1268.2	1268.2					3564.3	85.9%
Support									0	0.0%
Comms		114.24	114.24	114.24					342.72	8.3%
Total/sqm		1382.44	1382.44	1382.44					4147.32	
Building totals										
Wards		3979.102	4108.53	4108.67					12196.302	57.3%
OPD	624.6								624.6	2.9%
Pathology	59.5	240.3							299.8	1.4%
Pharmacy	160								160	0.8%
Theatres				49					49	0.2%
Support	1946.37	974.8	667.1	441.7	1159.38				5189.35	24.4%
Plant	95.79								95.79	0.5%
Comms	502.93	778.53	657.24	657.24	71.4				2667.34	12.5%
Total/sqm	3389.19	5972.732	5432.87	5256.61	1230.78				21282.182	
Wards,OPD, support	2570.97	4953.902	4775.63	4550.37	1159.38				18010.252	84.6%
High tech	219.5	240.3	0	49					508.8	2.4%
Plant/Comms.	598.72	778.53	657.24	657.24	71.4				2763.13	13.0%
Total area/sqm									21282.182	
Total area/sqm ex.Plant/Comms.									18519.052	
Wards,OPD, support									18010.252	97.3%
High tech									508.8	2.7%

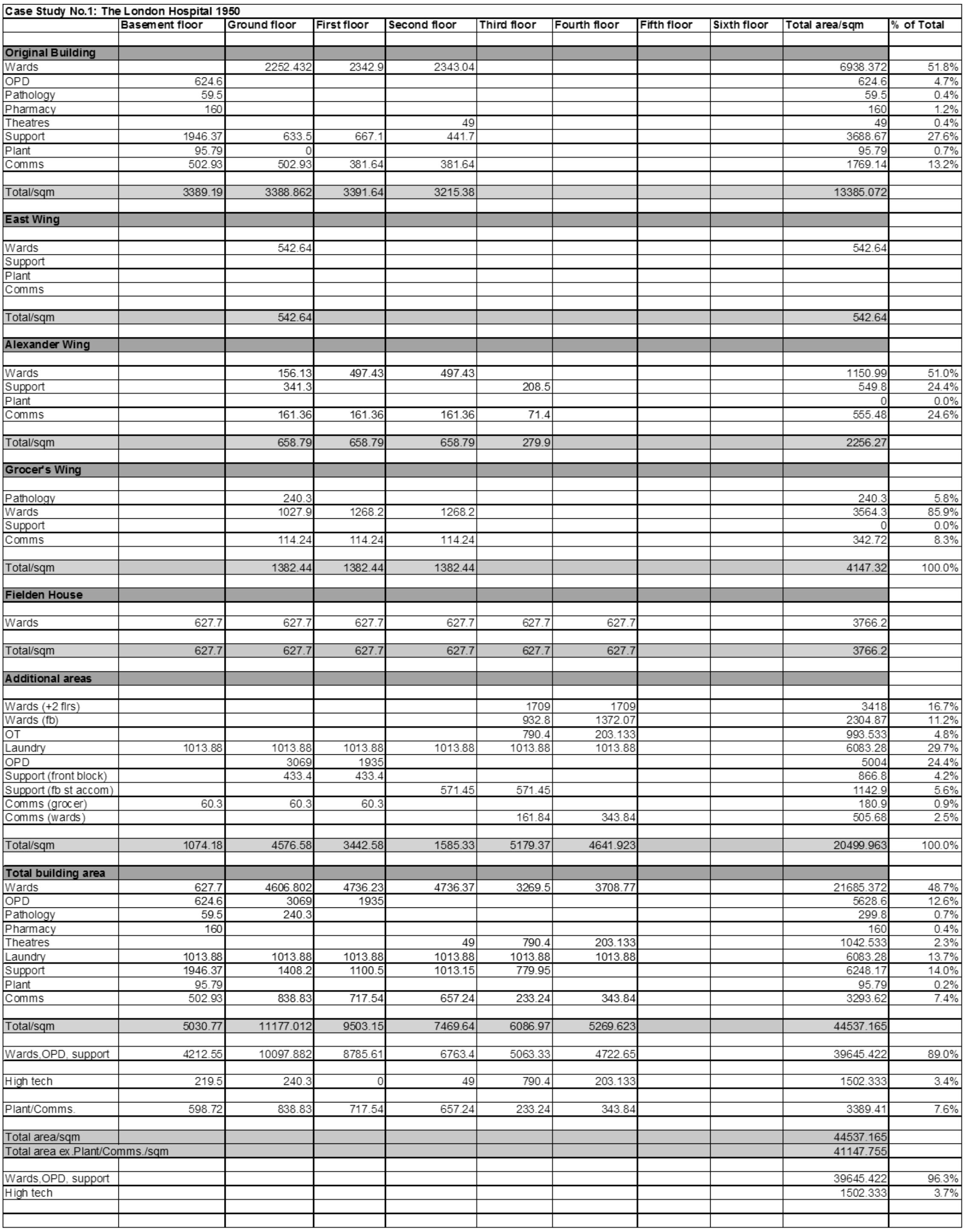
Appendix F.13 1886, Tabled results from measured drawings.

6.2.2 The RLH: Analysis of measured plans

Case Study No.1: The London Hospital 1900										
	Basement floor	**Ground floor**	**First floor**	**Second floor**	**Third floor**	**Fourth floor**	**Fifth floor**	**Sixth floor**	**Total area/sqm**	**% of total**
Original Building										
Wards		2252.432	2342.9	2343.04					6938.372	51.8%
OPD	624.6								624.6	4.7%
Pathology	59.5								59.5	0.4%
Pharmacy	160								160	1.2%
Theatres				49					49	0.4%
Support	1946.37	633.5	667.1	441.7					3688.67	27.6%
Plant	95.79	0							95.79	0.7%
Comms	502.93	502.93	381.64	381.64					1769.14	13.2%
Total/sqm	3389.19	3388.862	3391.64	3215.38					13385.072	
East Wing										
Wards		542.64							542.64	
Support										
Plant										
Comms										
Total/sqm		542.64							542.64	
Alexander Wing										
Wards		156.13	497.43	497.43					1150.99	51.0%
Support		341.3			208.5				549.8	24.4%
Plant									0	0.0%
Comms		161.36	161.36	161.36	71.4				555.48	24.6%
Total/sqm		658.79	658.79	658.79	279.9				2256.27	
Grocer's Wing										
Pathology		240.3							240.3	
Wards		1027.9	1268.2	1268.2					3564.3	
Support									0	
Comms		114.24	114.24	114.24					342.72	
Total/sqm		1382.44	1382.44	1382.44					4147.32	
Fielden House										
Wards		627.7	627.7	627.7					1883.1	
Total/sqm		627.7	627.7	627.7					1883.1	
Additional areas										
Wards (+2 flrs)					1709	1709			3418	
Wards (fb)					932.8	1372.07			2304.87	
OT					790.4	203.133			993.533	
Laundry	1013.88	1013.88	1013.88	1013.88	1013.88	1013.88			6083.28	
OPD		3069	1935						5004	
Support (front block)		433.4	433.4						866.8	
Support (fb st accom)				571.45	571.45				1142.9	
Comms (grocer)	60.3	60.3	60.3						180.9	
Comms (wards)					161.84	343.84			505.68	
Total/sqm	1074.18	4576.58	3442.58	1585.33	5179.37	4641.923			20499.963	
Total building area										
Wards		4606.802	4736.23	4736.37	2641.8	3081.07			19802.272	46.4%
OPD	624.6	3069	1935						5628.6	13.2%
Pathology	59.5	240.3							299.8	0.7%
Pharmacy	160								160	0.4%
Theatres				49	790.4	203.133			1042.533	2.4%
Laundry	1013.88	1013.88	1013.88	1013.88	1013.88	1013.88			6083.28	14.3%
Support	1946.37	1408.2	1100.5	1013.15	779.95				6248.17	14.6%
Plant	95.79								95.79	0.2%
Comms	502.93	838.83	717.54	657.24	233.24	343.84			3293.62	7.7%
Total/sqm	4403.07	11177.012	9503.15	7469.64	5459.27	4641.923			42654.065	
Wards,OPD, support	3584.85	10097.882	8785.61	6763.4	4435.63	4094.95			37762.322	88.5%
High tech	219.5	240.3	0	49	790.4	203.133			1502.333	3.5%
Plant/Comms.	598.72	838.83	717.54	657.24	233.24	343.84			3389.41	7.9%
Total area/sqm									42654.065	
Total area ex.Plant/Comms./sqm									39264.655	
Wards,OPD, support									37762.322	96.2%
High tech									1502.333	3.8%

Appendix F.14 1900, Tabled results from measured drawings.

6.2.2 The RLH: Analysis of measured plans



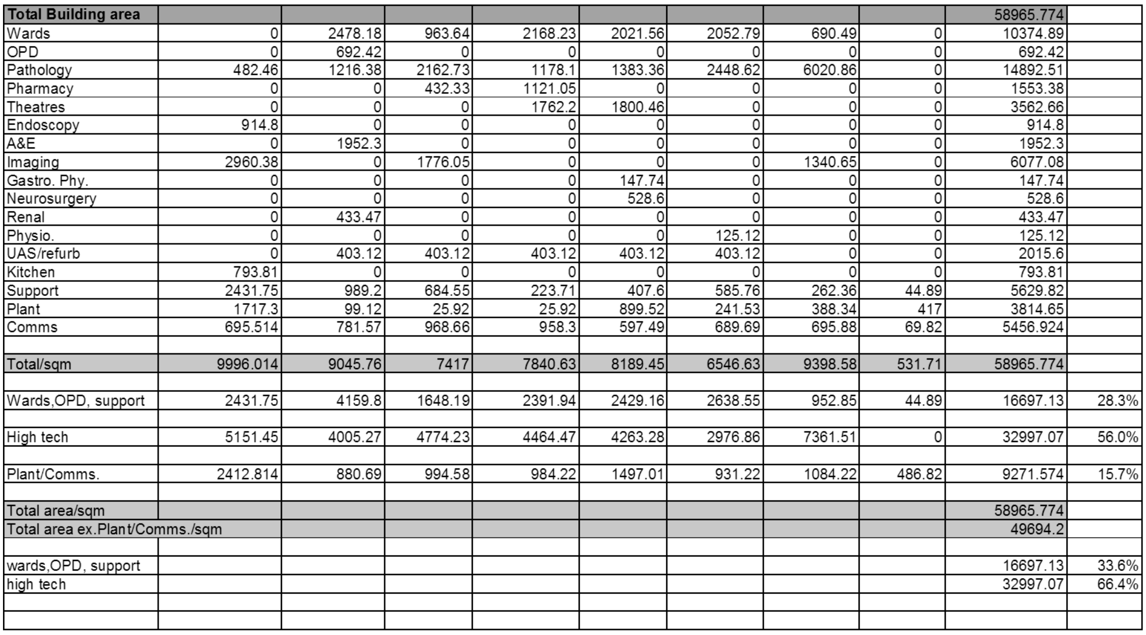
Case Study No.1: The London Hospital 1950										
	Basement floor	**Ground floor**	**First floor**	**Second floor**	**Third floor**	**Fourth floor**	**Fifth floor**	**Sixth floor**	**Total area/sqm**	**% of Total**
Original Building										
Wards		2252.432	2342.9	2343.04					6938.372	51.8%
OPD	624.6								624.6	4.7%
Pathology	59.5								59.5	0.4%
Pharmacy	160								160	1.2%
Theatres				49					49	0.4%
Support	1946.37	633.5	667.1	441.7					3688.67	27.6%
Plant	95.79	0							95.79	0.7%
Comms	502.93	502.93	381.64	381.64					1769.14	13.2%
Total/sqm	3389.19	3388.862	3391.64	3215.38					13385.072	
East Wing										
Wards		542.64							542.64	
Support										
Plant										
Comms										
Total/sqm		542.64							542.64	
Alexander Wing										
Wards		156.13	497.43	497.43					1150.99	51.0%
Support		341.3			208.5				549.8	24.4%
Plant									0	0.0%
Comms		161.36	161.36	161.36	71.4				555.48	24.6%
Total/sqm		658.79	658.79	658.79	279.9				2256.27	
Grocer's Wing										
Pathology		240.3							240.3	5.8%
Wards		1027.9	1268.2	1268.2					3564.3	85.9%
Support									0	0.0%
Comms		114.24	114.24	114.24					342.72	8.3%
Total/sqm		1382.44	1382.44	1382.44					4147.32	100.0%
Fielden House										
Wards	627.7	627.7	627.7	627.7	627.7	627.7			3766.2	
Total/sqm	627.7	627.7	627.7	627.7	627.7	627.7			3766.2	
Additional areas										
Wards (+2 flrs)					1709	1709			3418	16.7%
Wards (fb)					932.8	1372.07			2304.87	11.2%
OT					790.4	203.133			993.533	4.8%
Laundry	1013.88	1013.88	1013.88	1013.88	1013.88	1013.88			6083.28	29.7%
OPD		3069	1935						5004	24.4%
Support (front block)		433.4	433.4						866.8	4.2%
Support (fb st accom)				571.45	571.45				1142.9	5.6%
Comms (grocer)	60.3	60.3	60.3						180.9	0.9%
Comms (wards)					161.84	343.84			505.68	2.5%
Total/sqm	1074.18	4576.58	3442.58	1585.33	5179.37	4641.923			20499.963	100.0%
Total building area										
Wards	627.7	4606.802	4736.23	4736.37	3269.5	3708.77			21685.372	48.7%
OPD	624.6	3069	1935						5628.6	12.6%
Pathology	59.5	240.3							299.8	0.7%
Pharmacy	160								160	0.4%
Theatres				49	790.4	203.133			1042.533	2.3%
Laundry	1013.88	1013.88	1013.88	1013.88	1013.88	1013.88			6083.28	13.7%
Support	1946.37	1408.2	1100.5	1013.15	779.95				6248.17	14.0%
Plant	95.79								95.79	0.2%
Comms	502.93	838.83	717.54	657.24	233.24	343.84			3293.62	7.4%
Total/sqm	5030.77	11177.012	9503.15	7469.64	6086.97	5269.623			44537.165	
Wards,OPD, support	4212.55	10097.882	8785.61	6763.4	5063.33	4722.65			39645.422	89.0%
High tech	219.5	240.3	0	49	790.4	203.133			1502.333	3.4%
Plant/Comms.	598.72	838.83	717.54	657.24	233.24	343.84			3389.41	7.6%
Total area/sqm									44537.165	
Total area ex.Plant/Comms./sqm									41147.755	
Wards,OPD, support									39645.422	96.3%
High tech									1502.333	3.7%

Appendix F.15 1950, Tabled results from measured drawings.

6.2.2 The RLH: Analysis of measured plans

Case Study No.1: The London Hospital 2000										
	Basement floor	**Ground floor**	**First floor**	**Second floor**	**Third floor**	**Fourth floor**	**Fifth floor**	**Sixth floor**	**Total area/sqm**	**% of total**
Alexandra Wing										
Endoscopy	914.8								914.8	
A&E		1952.3							1952.3	
Imaging			1776.05						1776.05	
Theatres				1762.2					1762.2	
Gastro. Phy.					147.74				147.74	
Neurosurgery					528.6				528.6	
Labs						1660.9			1660.9	
Labs					205.26				205.26	
Nuclear Medicine							1340.65		1340.65	
Wards		529.79							529.79	
Support	656.81							44.89	701.7	
Plant	808.67				873.6			417	2099.27	
Comms	77.044	104.89	276.16	290	296.43	321.48	327.62	69.82	1763.444	
Total/sqm	2457.324	2586.98	2052.21	2052.2	2051.63	1982.38	1668.27	531.71	15382.704	
West Wing										
Renal		433.47							433.47	
Ward		301.51	417.2	417.2	439.08	442.45	89.76		2107.2	
Unused		403.12	403.12	403.12	403.12	403.12			2015.6	
Plant	239.12	76.72	3.52	3.52	3.52	3.52	3.52		333.44	
Support	963.06								963.06	
Comms	58.2						43.96		102.16	
Total/sqm	1260.38	1214.82	823.84	823.84	845.72	849.09	137.24		5954.93	
Front Block										
Radiotherapy	1149.31								1149.31	
Support	552.49	989.2	31.78	223.71		585.76			2382.94	
Wards		311.13		410.37					721.5	
Pharmacy			432.33	1121.05					1553.38	
Pathology			984.63						984.63	
Theatres					1800.46				1800.46	
Physio						125.12			125.12	
Plant	34.5					215.61			250.11	
Comms	185.39	608.7	520.54	508.22	99.88	280.23			2202.96	
Total/sqm	1921.69	1909.03	1969.28	2263.35	1900.34	1206.72			11170.41	
East Wing										
Linac Suite	227.03								227.03	
Radiotherapy	206.25								206.25	
Support	23.3		104				262.36		389.66	
Kitchen	793.81								793.81	
Wards		695.98	546.44	784.39	780.1	807.96			3614.87	
OPD		692.42							692.42	
Plant	81.95	22.4	22.4	22.4	22.4	22.4	22.4		216.35	
Comms	124.4	67.98	99.48	103.98	118.78	87.98	86.78		689.38	
Total/sqm	1456.74	1478.78	772.32	910.77	921.28	918.34	371.54		6829.77	
Grocer's Wing										
Imaging	1012.9								1012.9	
Wards		639.77		556.27					1196.04	
Support			548.77		407.6				956.37	
Comms	12.96		72.48	56.1	82.4				223.94	
Total/sqm	1025.86	639.77	621.25	612.37	490	0	0	0	3389.25	
Holland Wing										
Cardio/Ultrasound	364.89								364.89	
Support	236.09								236.09	
Plant	190.64								190.64	
Total/sqm	791.62								791.62	
Link Block										
wards					802.38	802.38	600.73		2205.49	
Total/sqm					802.38	802.38	600.73		2205.49	
Pathology Block										
Pathology Block	482.46	1216.38	1178.1	1178.1	1178.1	787.72	6020.86		12041.72	
comms	237.52						237.52		475.04	
Plant	362.42						362.42		724.84	
Total/sqm	1082.4	1216.38	1178.1	1178.1	1178.1	787.72	6620.8		13241.6	

6.2.2 The RLH: Analysis of measured plans



Total Building area									58965.774	
Wards	0	2478.18	963.64	2168.23	2021.56	2052.79	690.49	0	10374.89	
OPD	0	692.42	0	0	0	0	0	0	692.42	
Pathology	482.46	1216.38	2162.73	1178.1	1383.36	2448.62	6020.86	0	14892.51	
Pharmacy	0	0	432.33	1121.05	0	0	0	0	1553.38	
Theatres	0	0	0	1762.2	1800.46	0	0	0	3562.66	
Endoscopy	914.8	0	0	0	0	0	0	0	914.8	
A&E	0	1952.3	0	0	0	0	0	0	1952.3	
Imaging	2960.38	0	1776.05	0	0	0	1340.65	0	6077.08	
Gastro. Phy.	0	0	0	0	147.74	0	0	0	147.74	
Neurosurgery	0	0	0	0	528.6	0	0	0	528.6	
Renal	0	433.47	0	0	0	0	0	0	433.47	
Physio.	0	0	0	0	0	125.12	0	0	125.12	
UAS/refurb	0	403.12	403.12	403.12	403.12	403.12	0	0	2015.6	
Kitchen	793.81	0	0	0	0	0	0	0	793.81	
Support	2431.75	989.2	684.55	223.71	407.6	585.76	262.36	44.89	5629.82	
Plant	1717.3	99.12	25.92	25.92	899.52	241.53	388.34	417	3814.65	
Comms	695.514	781.57	968.66	958.3	597.49	689.69	695.88	69.82	5456.924	
Total/sqm	9996.014	9045.76	7417	7840.63	8189.45	6546.63	9398.58	531.71	58965.774	
Wards,OPD, support	2431.75	4159.8	1648.19	2391.94	2429.16	2638.55	952.85	44.89	16697.13	28.3%
High tech	5151.45	4005.27	4774.23	4464.47	4263.28	2976.86	7361.51	0	32997.07	56.0%
Plant/Comms.	2412.814	880.69	994.58	984.22	1497.01	931.22	1084.22	486.82	9271.574	15.7%
Total area/sqm									58965.774	
Total area ex.Plant/Comms./sqm									49694.2	
wards,OPD, support									16697.13	33.6%
high tech									32997.07	66.4%

Appendix F.16 2000, Tabled results of measured drawings.

	% Low tech	**% Plant/Comms.**	**% High tech**	**% FM**
1832	90.1	7.9	2.0	n/a
1886	84.6	13.0	2.4	n/a
1900	88.53	7.95	3.52	n/a
1950	89.0	7.6	3.4	n/a
2000	28.3	15.7	56.0	n/a
2012	39.2	25.8	30.5	4.5

Appendix F.18 1832-2012 including Plant/Comms./FM

	% Low tech	**% High tech**
1832	97.8	2.2
1886	97.3	2.7
1900	96.2	3.8
1950	96.3	3.7
2000	33.6	66.4
2012	56.3	43.7

Appendix F.19 1832-2012 excluding Plant/Comms./FM

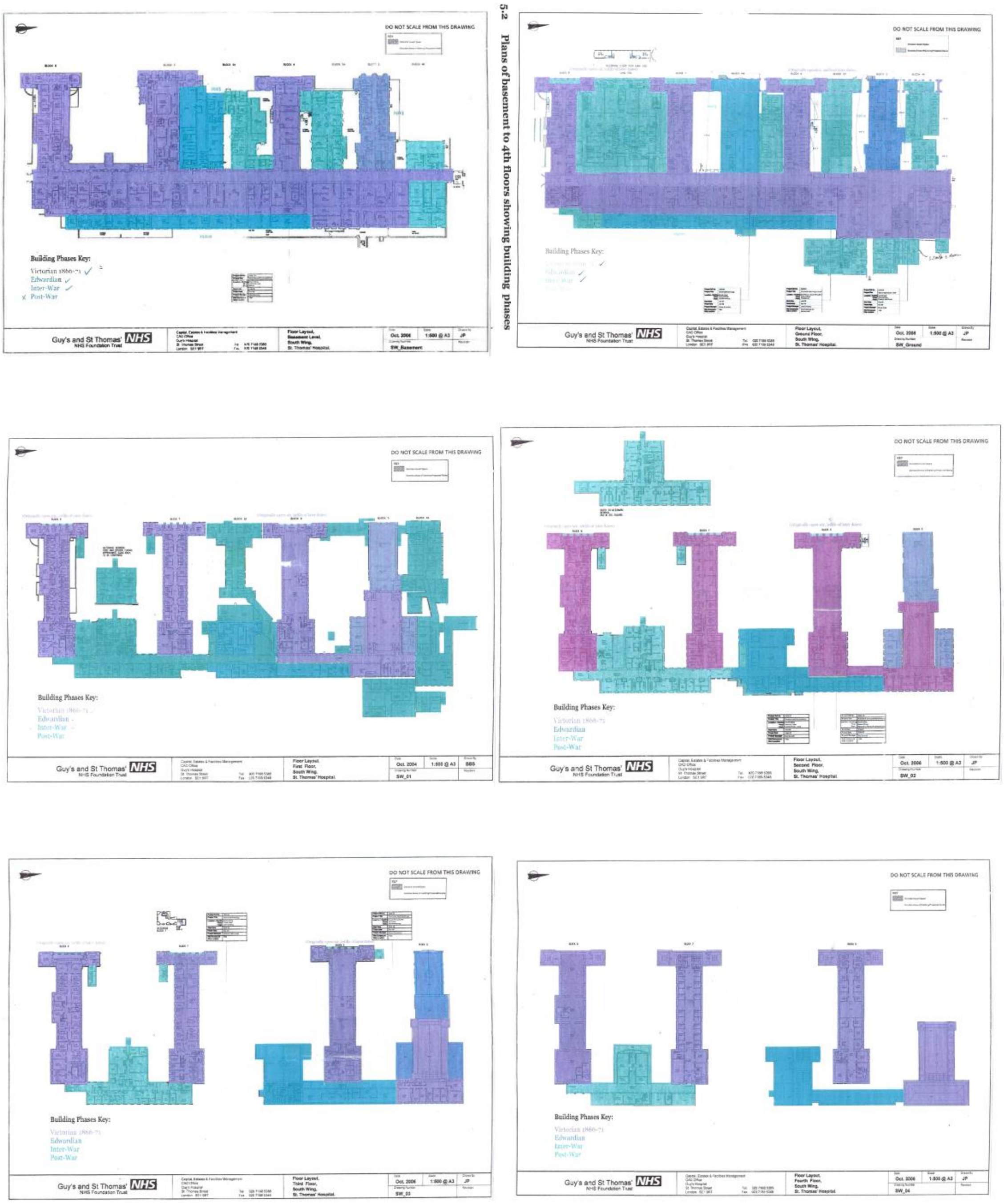
6.2.2 The RLH: Analysis of measured plans

Case Study No.1: The London Hospital 2012

	Comms	Plant	FM	OPD	OPD	OPD	Dis-charge	A&E	Imaging	Clinical Physics	CCU	Theatres	Sat Pharm	Maternity	wards	support	trauma	Total /sqm	% of total
New Building																			
Basement floor	1847.06	2019.68	2689.3															6556.04	6.5%
Ground floor	3475	258.32	747.52	1265.1	1900.6		151.68	5214.7										13012.92	12.8%
1st level	1293.14	2110.18	100.72	1821.7					6090.42	1949.66								13365.84	13.2%
2nd level	1169.94	528.1	152.58	1767.6	5515.1	2109.5												11242.88	11.1%
3rd level	1192.74	416.02	199.06	1807.6							2128.8	5433.9						11178.1	11.0%
4th level	756	1609.36	278.08								3636.22	4109.04						10388.7	10.2%
5th level	749.92	7255.6	752.02										224.56					8982.1	8.9%
6th level (Paeds)	755.68	289.32	175.44	2155.4	1084.4							1560.32		2258.94				8279.5	8.2%
7th level (women)	677.76	362.2	145.88	2077.4											3754.1	991.4		8008.7	7.9%
8th level (paeds)	667.68	361.78	104.52	2054.3											5076.96	49		8314.26	8.2%
9th level (renal)	645.52	343.06	148.08	4277.4											2531.48			7945.5	7.8%
10th level	553.52	4140.42	58.64												2461.18			7213.76	7.1%
11th level	514.64	697.14	102.96												4618.2			5932.94	5.8%
12th level	458.64	227.34	154.28												3372.76		1154.8	5367.82	5.3%
13th level	458.64	224.14	135.72												4467.56			5286.06	5.2%
14th level	458.64	224.14	135.72												4467.56			5286.06	5.2%
15th level	458.64	224.14	135.72												4467.56			5286.06	5.2%
16th level	458.64	224.14	135.72												4467.56			5286.06	5.2%
17th level	393.72	4574.5																4968.22	4.9%
18th level	220	1094.24	202.08															1516.32	1.5%
Total/sqm	17205.52	27183.82	6554.04	17227	8500.1	2109.5	151.68	5214.7	6090.42	1949.66	5765.02	11103.26	224.56	2258.94	39684.9	1040.4	1154.8	153417.8	
% of GBA	11.2%	17.7%	4.3%	11.2%	5.5%	1.4%	0.1%	3.4%	4.0%	1.3%	3.8%	7.2%	0.1%	1.5%	25.9%	0.7%	0.8%	100.0%	
Total(ex.Comms/Plant/FM)/sqm				17227	8500.1	2109.5	151.68	5214.7	6090.42	1949.66	5765.02	11103.26	224.56	2258.94	39684.9		1154.8	101434.1	
% of GBA				17.0%	8.4%	2.1%	0.1%	5.1%	6.0%	1.9%	5.7%	10.9%	0.2%	2.2%	39.1%		1.1%	100.0%	
High tech								5214.68	6090.42	1949.66	5765.02	11103.26	224.56	2258.94			1154.80	33761.34	
								3.4%	4.0%	1.3%	3.8%	7.2%	0.1%	1.5%			0.8%		22.0%
Wards, OPD, support				17227	8500.1	2109.5									39684.9			67521.04	
				11.2%	5.5%	1.4%									25.9%				44.0%
FM			6554.04				151.68									1040.4		7746.12	
			4.3%				0.1%									0.7%			5.0%
Plant/ Comms.	17205.52	27183.82																44389.34	
	11.2%	17.7%																	28.9%
Total/sqm																		153417.8	100.0%
High tech								5214.68	6090.42	1949.66	5765.02	11103.26	224.56	2258.94			1154.80	33761.34	33.3%
Wards, OPD, support				17227	8500.1	2109.5									39684.9			67521.04	66.7%
Total ex. Plant/Comms.&FM/sqm																		101282.38	
Additional departments in existing campus																		Total	
Pathology/ pharmacy	15,726.24																	15,726.24	
Endoscopy	914.8																	914.8	
Renal	433.47																	433.47	
Linac Suite	227.03																	227.03	
Radio-therapy	206.25	1149.31																1355.56	
Support	23.3																	23.3	
Total/sqm																		18680.4	
Combined totals/sqm																		172098.2	
Combind totals (ex. Comms/Plant/FM)/sqm																		120114.5	
High tech	18,680.40							5214.68	6090.42	1949.66	5765.02	11103.26	224.56	2258.94			1154.80	52441.74	
	10.9%							3.0%	3.5%	1.1%	3.3%	6.5%	0.1%	1.3%			0.7%		30.5%
Wards, OPD, support				17227	8500.1	2109.5									39684.9			67521.04	
				10.0%	4.9%	1.2%									23.1%				39.2%
FM			6554.04				151.68									1040.4		7746.12	
			3.8%				0.1%									0.6%			4.5%
Plant/Comms.	17205.52	27183.82																44389.34	
	10.0%	15.8%																	25.8%
Total/sqm																		172098.2	100.0%
High tech	18,680.40							5214.68	6090.42	1949.66	5765.02	11103.26	224.56	2258.94			1154.80	52441.74	43.7%
Wards, OPD, support				17227	8500.1	2109.5									39684.9			67521.04	56.3%
Total ex. Plant/Comms.&FM/sqm																		119962.78	100.0%

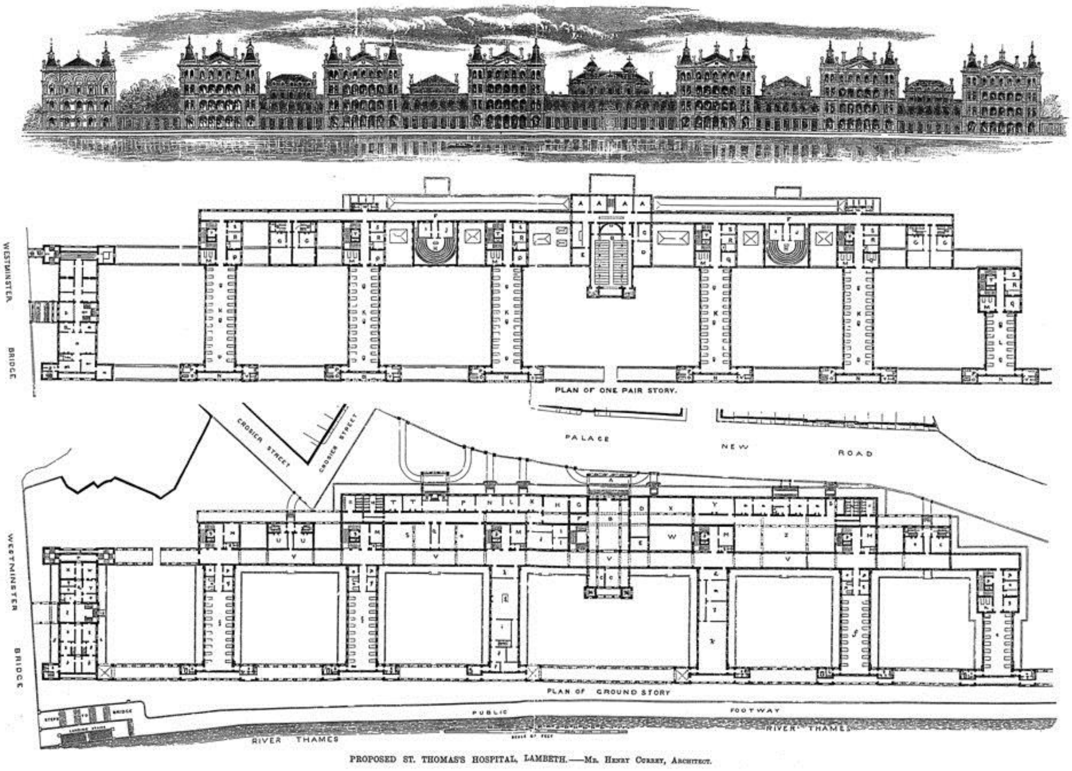
Appendix F.17 2012, Tabled results from measured drawings.

6.3.2 St. Thomas' Hospital: Analysis of measured plans

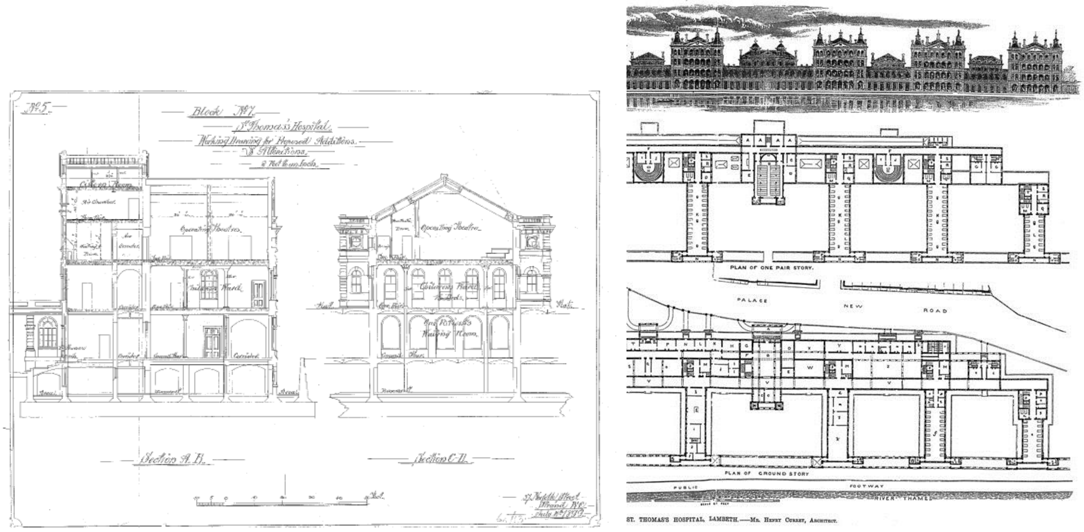


Appendix F.20 Plans of St. Thomas' showing building phases. Sourced: The Architectural History Practice Limited (2007) *St. Thomas' Hospital South Wing Statement of Significance*, pp.41-6.

6.3 Case Study No.2: St. Thomas' Hospital

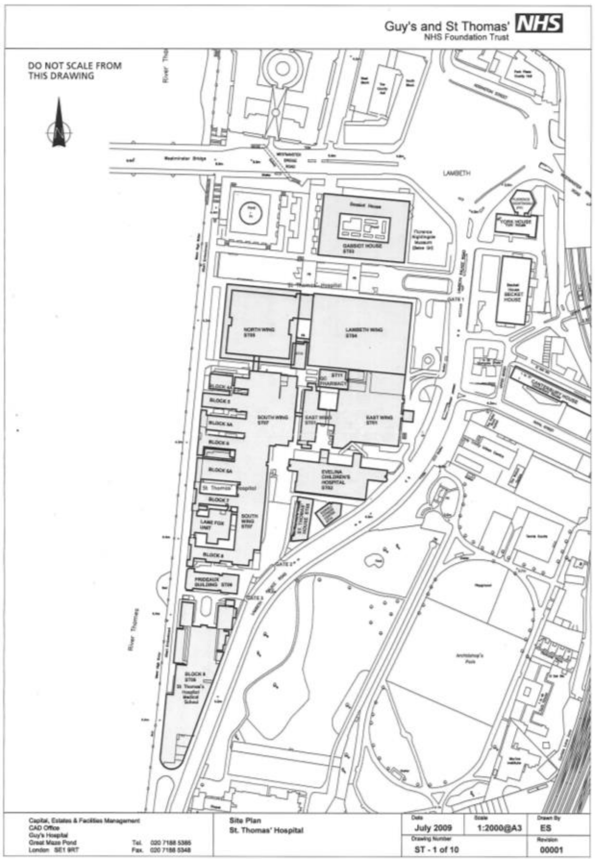


Appendix F.21 Ground Floor Plan, St. Thomas' Hospital, 1880 and 1900. No changes were recorded during this period (The Architectural History Practice Limited (2007) *St. Thomas's Hospital South Wing Statement of Significance*, p.31).

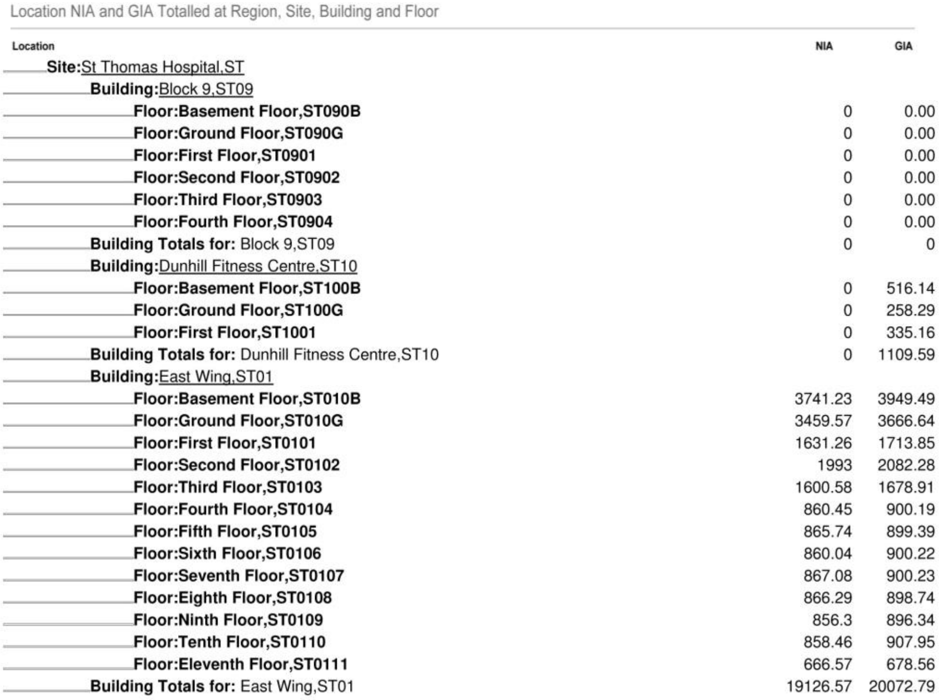


Appendix F.22 Left: 1899, Theatre room section. Highlights the number of storeys in building. Right: Ground Floor Plan, St. Thomas' Hospital, 1950 (Guys and St. Thomas' Capital Estate & Facilities Department).

6.3 Case Study No.2: St. Thomas' Hospital



Appendix F.23 2010, Ground Floor Master Plan, St. Thomas' Hospital (Guys and St. Thomas' Capital Estate & Facilities Department).

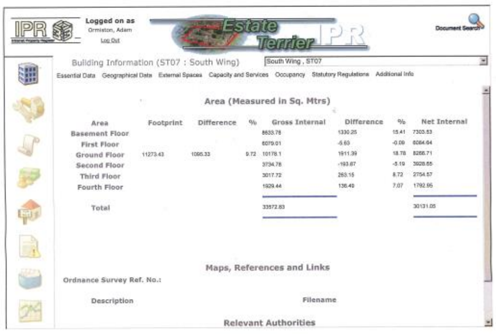


Location NIA and GIA Totalled at Region, Site, Building and Floor

Location	NIA	GIA
Site: St Thomas Hospital,ST		
Building: Block 9,ST09		
Floor:Basement Floor,ST090B	0	0.00
Floor:Ground Floor,ST090G	0	0.00
Floor:First Floor,ST0901	0	0.00
Floor:Second Floor,ST0902	0	0.00
Floor:Third Floor,ST0903	0	0.00
Floor:Fourth Floor,ST0904	0	0.00
Building Totals for: Block 9,ST09	0	0
Building: Dunhill Fitness Centre,ST10		
Floor:Basement Floor,ST100B	0	516.14
Floor:Ground Floor,ST100G	0	258.29
Floor:First Floor,ST1001	0	335.16
Building Totals for: Dunhill Fitness Centre,ST10	0	1109.59
Building: East Wing,ST01		
Floor:Basement Floor,ST010B	3741.23	3949.49
Floor:Ground Floor,ST010G	3459.57	3666.64
Floor:First Floor,ST0101	1631.26	1713.85
Floor:Second Floor,ST0102	1993	2082.28
Floor:Third Floor,ST0103	1600.58	1678.91
Floor:Fourth Floor,ST0104	860.45	900.19
Floor:Fifth Floor,ST0105	865.74	899.39
Floor:Sixth Floor,ST0106	860.04	900.22
Floor:Seventh Floor,ST0107	867.08	900.23
Floor:Eighth Floor,ST0108	866.29	898.74
Floor:Ninth Floor,ST0109	856.3	896.34
Floor:Tenth Floor,ST0110	858.46	907.95
Floor:Eleventh Floor,ST0111	666.57	678.56
Building Totals for: East Wing,ST01	19126.57	20072.79

Appendix F.24 Exemplar of Schedule of Accommodation (SOA) used for measured calculations (Guys and St. Thomas' Capital Estate & Facilities Department).

6.3.2 St. Thomas' Hospital: Analysis of measured plans



Building Information (ST07 : South Wing)

South Wing , ST07

Area (Measured in Sq. Mtrs)

Area	Footprint	Difference	%	Gross Internal	Difference	%	Net Internal
Basement Floor				8633.78	1330.25	15.41	7303.53
First Floor				6079.01	-5.63	-0.09	6084.64
Ground Floor	11273.43	1095.33	9.72	10178.1	1911.39	18.78	8266.71
Second Floor				3734.78	-193.87	-5.19	3928.65
Third Floor				3017.72	263.15	8.72	2754.57
Fourth Floor				1929.44	136.49	7.07	1792.95
Total				33572.83			30131.05

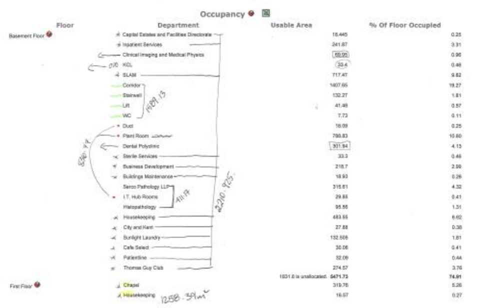
Maps, References and Links

Ordnance Survey Ref. No.:

Description

Filename

Relevant Authorities



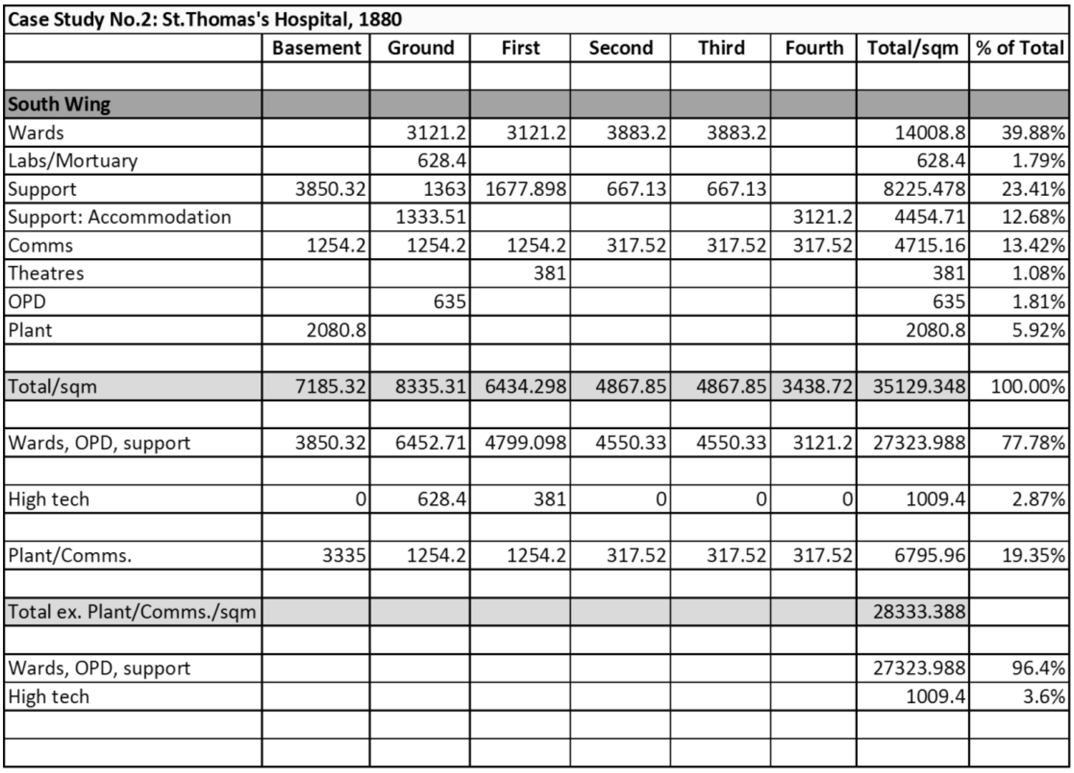
Occupancy

Floor	Department	Usable Area	% Of Floor Occupied
Basement Floor	Capital Estates and Facilities Directorate	18.445	0.25
	Inpatient Services	241.87	3.31
	Clinical Imaging and Medical Physics	69.95	0.96
	KCL	33.4	0.46
	SLAM	717.47	9.82
	Corridor	1407.65	19.27
	Stairwell	132.27	1.81
	Lift	41.49	0.57
	WC	7.73	0.11
	Duct	18.09	0.25
	Plant Room	788.83	10.80
	Dental Polyclinic	301.84	4.13
	Sterile Services	33.3	0.46
	Business Development	218.7	2.99
	Buildings Maintenance	18.93	0.26
	Serco Pathology LLP	315.61	4.32
	I.T. Hub Rooms	29.85	0.41
	Histopathology	95.56	1.31
	Housekeeping	483.55	6.62
	City and Kent	27.88	0.38
	Sunlight Laundry	132.508	1.81
	Cafe Select	30.06	0.41
	Patientline	32.09	0.44
	Thomas Guy Club	274.57	3.76
		1831.8 is unallocated. 5471.73	74.91
First Floor	Chapel	319.76	5.26
	Housekeeping	16.57	0.27

070
1589.13
836.77
441.02
2210.925
1258.39m²

Appendix F.25 Left: Exemplar used for departmental calculations for each floor. Right: Individual calculations done by hand (Guys and St. Thomas' Capital Estate & Facilities Department).

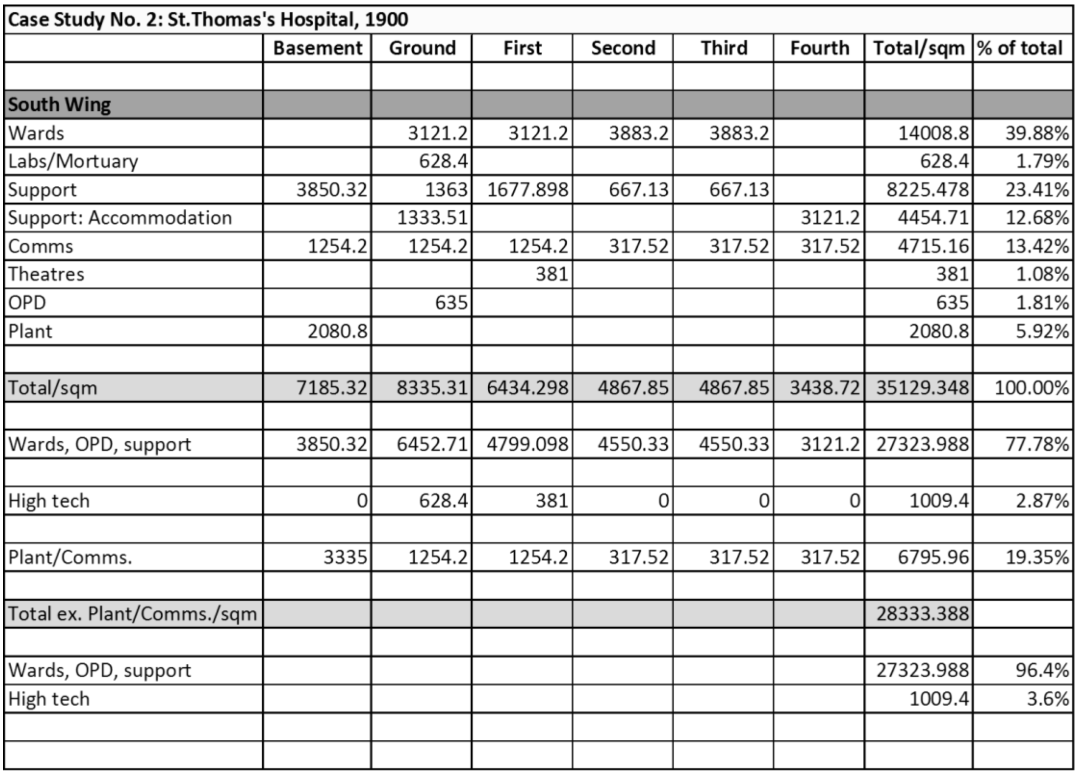
Left: Appendix F.26 Photograph of South Wing, St. Thomas' Hospital before the World War II bombing (Guys and St. Thomas' Capital Estate & Facilities Department).
Right: Appendix F.26a 2012, Photograph of North Wing, St. Thomas' Hospital.



Case Study No.2: St.Thomas's Hospital, 1880								
	Basement	Ground	First	Second	Third	Fourth	Total/sqm	% of Total
South Wing								
Wards		3121.2	3121.2	3883.2	3883.2		14008.8	39.88%
Labs/Mortuary		628.4					628.4	1.79%
Support	3850.32	1363	1677.898	667.13	667.13		8225.478	23.41%
Support: Accommodation		1333.51				3121.2	4454.71	12.68%
Comms	1254.2	1254.2	1254.2	317.52	317.52	317.52	4715.16	13.42%
Theatres			381				381	1.08%
OPD		635					635	1.81%
Plant	2080.8						2080.8	5.92%
Total/sqm	7185.32	8335.31	6434.298	4867.85	4867.85	3438.72	35129.348	100.00%
Wards, OPD, support	3850.32	6452.71	4799.098	4550.33	4550.33	3121.2	27323.988	77.78%
High tech	0	628.4	381	0	0	0	1009.4	2.87%
Plant/Comms.	3335	1254.2	1254.2	317.52	317.52	317.52	6795.96	19.35%
Total ex. Plant/Comms./sqm							28333.388	
Wards, OPD, support							27323.988	96.4%
High tech							1009.4	3.6%

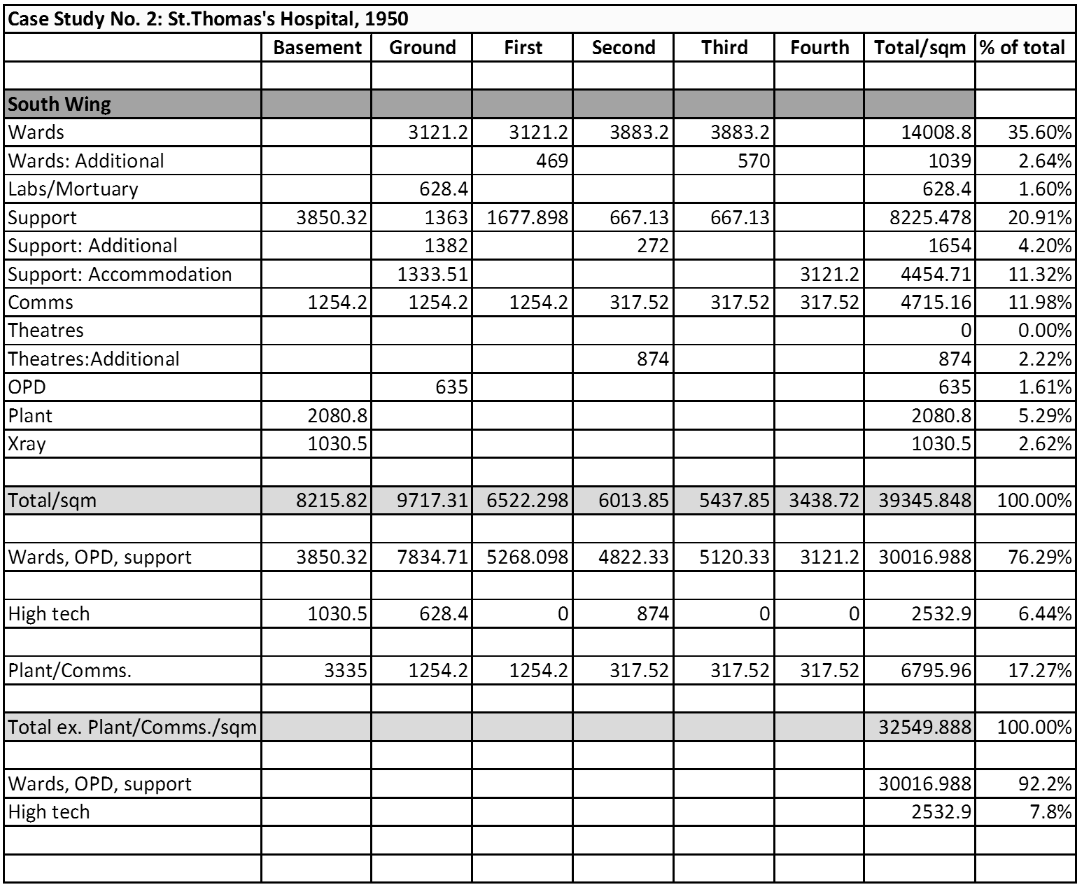
Appendix F.27 1880, SOA spread sheet for St. Thomas' Hospital.

6.3.2 St. Thomas' Hospital: Analysis of measured plans



Case Study No. 2: St.Thomas's Hospital, 1900								
	Basement	**Ground**	**First**	**Second**	**Third**	**Fourth**	**Total/sqm**	**% of total**
South Wing								
Wards		3121.2	3121.2	3883.2	3883.2		14008.8	39.88%
Labs/Mortuary		628.4					628.4	1.79%
Support	3850.32	1363	1677.898	667.13	667.13		8225.478	23.41%
Support: Accommodation		1333.51				3121.2	4454.71	12.68%
Comms	1254.2	1254.2	1254.2	317.52	317.52	317.52	4715.16	13.42%
Theatres			381				381	1.08%
OPD		635					635	1.81%
Plant	2080.8						2080.8	5.92%
Total/sqm	7185.32	8335.31	6434.298	4867.85	4867.85	3438.72	35129.348	100.00%
Wards, OPD, support	3850.32	6452.71	4799.098	4550.33	4550.33	3121.2	27323.988	77.78%
High tech	0	628.4	381	0	0	0	1009.4	2.87%
Plant/Comms.	3335	1254.2	1254.2	317.52	317.52	317.52	6795.96	19.35%
Total ex. Plant/Comms./sqm							28333.388	
Wards, OPD, support							27323.988	96.4%
High tech							1009.4	3.6%

Appendix F.28 1900, SOA spread sheet for St. Thomas'.



Case Study No. 2: St.Thomas's Hospital, 1950								
	Basement	**Ground**	**First**	**Second**	**Third**	**Fourth**	**Total/sqm**	**% of total**
South Wing								
Wards		3121.2	3121.2	3883.2	3883.2		14008.8	35.60%
Wards: Additional			469		570		1039	2.64%
Labs/Mortuary		628.4					628.4	1.60%
Support	3850.32	1363	1677.898	667.13	667.13		8225.478	20.91%
Support: Additional		1382		272			1654	4.20%
Support: Accommodation		1333.51				3121.2	4454.71	11.32%
Comms	1254.2	1254.2	1254.2	317.52	317.52	317.52	4715.16	11.98%
Theatres							0	0.00%
Theatres:Additional				874			874	2.22%
OPD		635					635	1.61%
Plant	2080.8						2080.8	5.29%
Xray	1030.5						1030.5	2.62%
Total/sqm	8215.82	9717.31	6522.298	6013.85	5437.85	3438.72	39345.848	100.00%
Wards, OPD, support	3850.32	7834.71	5268.098	4822.33	5120.33	3121.2	30016.988	76.29%
High tech	1030.5	628.4	0	874	0	0	2532.9	6.44%
Plant/Comms.	3335	1254.2	1254.2	317.52	317.52	317.52	6795.96	17.27%
Total ex. Plant/Comms./sqm							32549.888	100.00%
Wards, OPD, support							30016.988	92.2%
High tech							2532.9	7.8%

Appendix F.29 1950, SOA spread sheet for St. Thomas'.

6.3.2 St. Thomas’ Hospital: Analysis of measured plans

Case Study No. 2: St.Thomas's Hospital, 2010																	
	Basement	Ground	First	Second	Third	Fourth	5th	6th	7th	8th	9th	10th	11th	12th	13th	Total /sqm	% of Total
South Wing																	
Wards																0	0.00%
Pathology	411.17		571.63	526.01	21.885											1530.695	5.31%
Support	2210.925	1985.85	1258.39	458.3	484.9	336.82										6735.185	23.36%
Support: Accommodation																0	0.00%
Comms	1589.13	1952.03	1205.86	790.02	446.49	241.08										6224.61	21.59%
Theatres																0	0.00%
OPD	335.34	1800.71	1275.97	251.5	1640.25											5303.77	18.40%
Pharmacy				213.18												213.18	0.74%
Plant	836.77	21.5	58.67	76.38	48.21	430.38										1471.91	5.11%
Imaging	69.95															69.95	0.24%
UAS	1831.8	2314.3	327.06	1613.23	112.84	423.63										6622.86	22.97%
Refurb		122.36	176.5			361.04										659.9	2.29%
Total/sqm	7285.085	8196.75	4874.08	3928.62	2754.575	1792.95										28832.06	100.00%
QC Pharmacy																	
Pharmacy		351.48														351.48	100.00%
Total/sqm	0	351.48	0	0	0	0										351.48	100.00%
Twin modular theatres																	
Theatres		242.45														242.45	100.00%
Total/sqm	0	242.45	0	0	0	0										242.45	100.00%
Lambeth Wing																	
Wards																0	0.00%
Pathology		163.8			26.65											190.45	0.58%
Support	3064.05	482.81	48.68	50.7	199.89	2.97										3849.1	11.68%
Support: Accommodation																0	0.00%
Comms	748.72	793.11	722.31	298.2	798.25	1019.58	79.3									4459.47	13.53%
Theatres				3138.7												3138.7	9.52%
OPD	123.74	384.6	644.79	1230.89	3739.56	3322.1										9445.68	28.66%
Pharmacy	540.29	650.08														1190.37	3.61%
Plant	289.9	148.85	187.09	195.45	166.84	201.9	2977.55									4167.58	12.65%
Imaging	515.69		3310.76													3826.45	11.61%
UAS		2213.9			9.09	384.34										2607.33	7.91%
Refurb		81.5														81.5	0.25%
Total/sqm	5282.39	4918.65	4913.63	4913.94	4940.28	4930.89	3056.85									32956.63	100.00%
North Wing																	
Wards											2947.69	2265.43	2931.94	1442.1		9587.18	18.61%
Pathology				1490.6		2320.11	2392.69									6203.4	12.04%
Support	1513.05	1526.51	857.35	156.66		100.84	10.31	33.81			46.68	40.64	76.82	724.12		5086.79	9.87%
Support: Accommodation																0	0.00%
Comms	1125.44	861.52	740.79	801.19	95.56	532.99	1052.85	303.11	374.29	301.63	465.57	1054.8	295.99	654.28	73.96	8733.97	16.95%
Theatres										265.69						265.69	0.52%
OPD			122.05								14.19		117.18	388.75		642.17	1.25%
Pharmacy																0	0.00%
Plant	426.16	146.21	151.09	167.57	3251.71	191.67	197.91	152.16	116.44	117.79	189.82	176.36	176.94	183.51	1233.4	6878.76	13.35%
Imaging	1603.59															1603.59	3.11%
UAS	1108.07	547.8	397.04	142.12		491.03			1725.79	2983.55		139.09	60.19	286.09		7880.77	15.29%
Refurb																0	0.00%
Maternity								3190.03	1454.73							4644.76	9.01%
Total/sqm	5776.31	3082.04	2268.32	2758.14	3347.27	3636.64	3653.76	3679.11	3671.25	3668.66	3663.95	3676.32	3659.06	3678.9	1307.4	51527.08	100.00%
East Wing																	
Wards					607.37		705.54		694.16	696.21	693.43	693.53				4090.24	21.66%
Pathology		9.45	25.17	5.95												40.57	0.21%
Support	1413.37	188.48	16.08	6	5.84	31.77		11.84	1.86	12.01	3.46					1690.71	8.95%
Support: Accommodation																0	0.00%
Comms	538.8	450.26	293.05	156.43	271.95	123.04	122.71	124.4	126.67	122.75	124.18	130.34	481.76			3066.34	16.24%
Theatres			268.81	1727.59		686.27		688.92								3371.59	17.86%
OPD		237			234.85											471.85	2.50%
Pharmacy																0	0.00%
Plant	1257.94	52.79	60.62	63.23	480.57	47.83	37.49	34.88	44.42	35.32	35.23	34.59	181.05			2365.96	12.53%
Imaging																0	0.00%
UAS	193.45															193.45	1.02%
Refurb	67.67			33.8												101.47	0.54%
Maternity																0	0.00%
A&E		2521.59														2521.59	13.35%
ICU			967.53													967.53	5.12%
Total/sqm	3471.23	3459.57	1631.26	1993	1600.58	888.91	865.74	860.04	867.11	866.29	856.3	858.46	662.81			18881.3	100.00%
Wards, OPD, support	8660.475	6605.96	4223.31	2154.05	6912.66	3794.5	715.85	45.65	696.02	708.22	3705.45	2999.6	3125.94	2555	0	46902.675	35.32%
High tech	3140.69	3938.85	5143.9	7102.03	48.535	3006.38	2392.69	3878.95	1454.73	265.69	0	0	0	0	0	30372.445	22.87%
																0	
Plant/Comms.	6812.86	4426.27	3419.48	2548.47	5559.58	2788.47	4467.81	614.55	661.82	577.49	814.8	1396.09	1135.74	837.79	1307.4	37368.6	28.14%
																0	
UAS and refurb	3200.99	5279.86	900.6	1789.15	121.93	1660.04	0	0	1725.79	2983.55	0	139.09	60.19	286.09	0	18147.28	13.67%
Total/sqm																132791	
Total without Plant/Comms./UAS and refurb/sqm																77275.12	
Wards, OPD, support																46902.675	60.7%
High tech																30372.445	39.3%

Appendix F.30 2010, SOA spread sheet for St. Thomas’ Hospital.

6.3.2 St. Thomas' Hospital: Analysis of measured plans

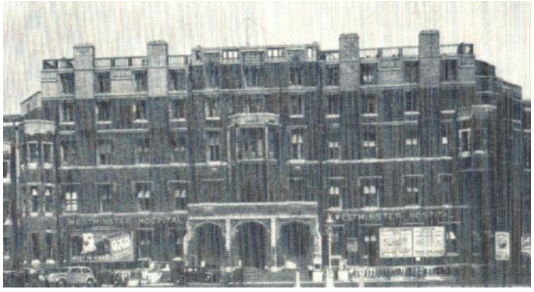
Year	% Low tech	% Plant/Comms.	% High tech	UAS/refurb.
1880	77.78	19.35	2.87	n/a
1900	77.78	19.35	2.87	n/a
1950	76.29	17.27	6.44	n/a
2010	35.32	28.14	22.9	13.67

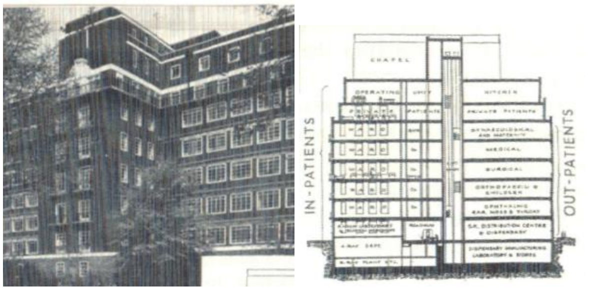
Appendix F.31 1880-2010 including Plant/Comms./UAS/refurb.

Year	% Low tech	% High tech
1880	96.4	3.6
1900	96.4	3.6
1950	92.2	7.8
2010	60.7	39.3

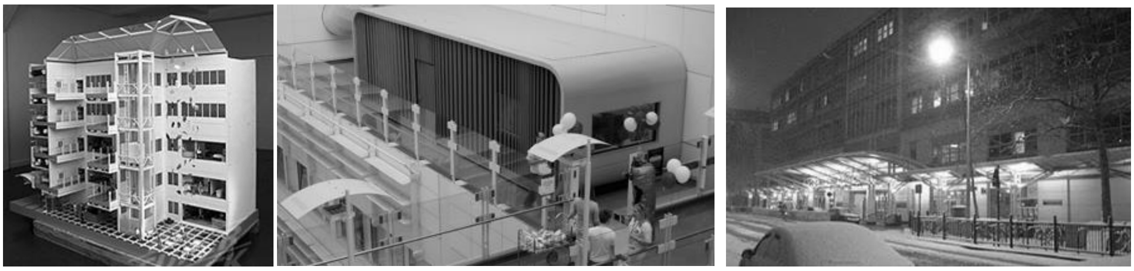
Appendix F.32 1880-2010 excluding Plant/Comms./UAS/refurb.

6.4 Case Study No.3: Chelsea and Westminster Hospital



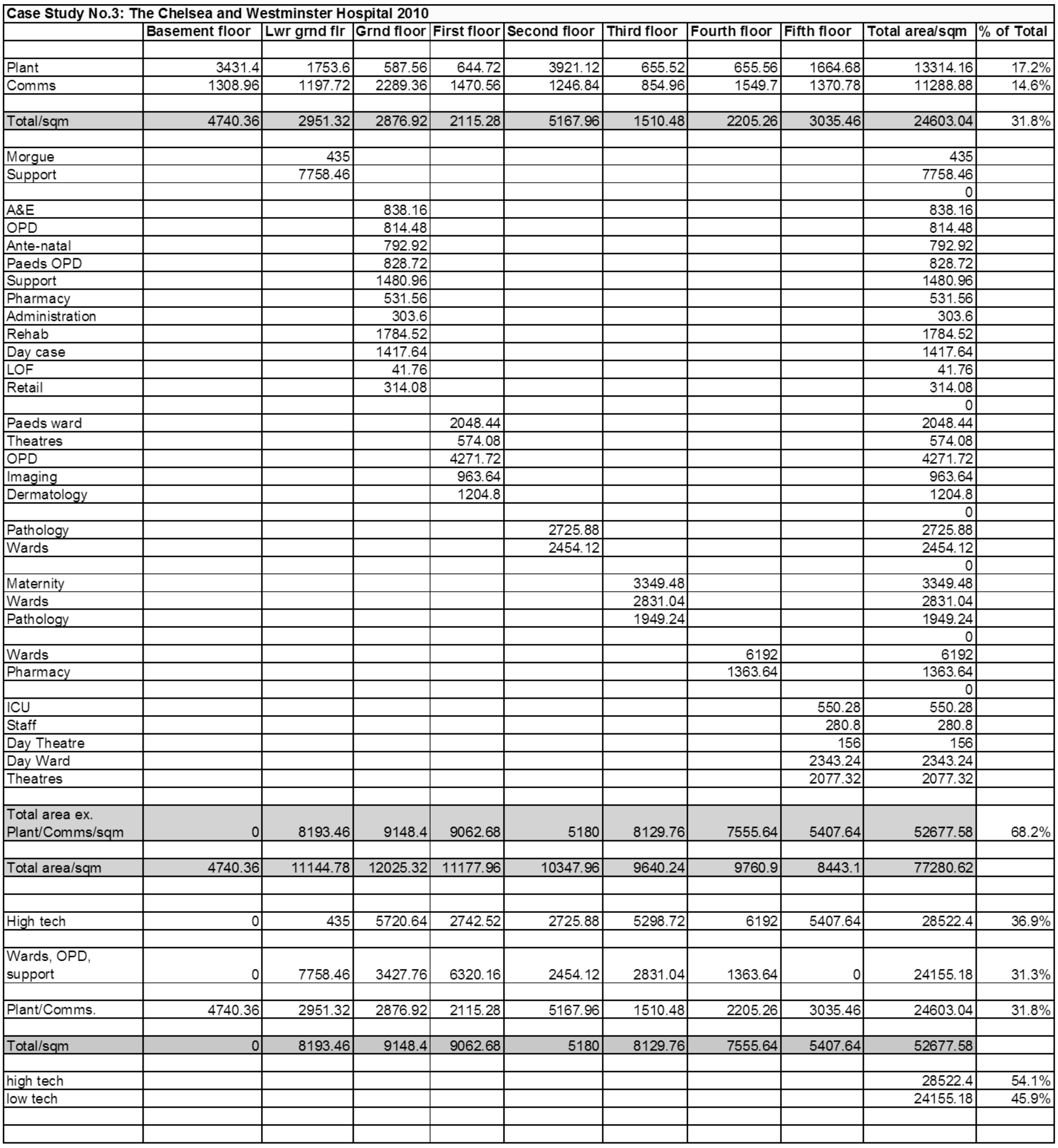


Left: Appendix F.33 Historical urban block of Westminster Hospital (1930s). **Middle to right:** Westminster Hospital (1965) (Barry & Carruthers, 2005:64).



Left to right: Appendix F.34 Top Sectional model through central hospital atrium. The radio pod in Chelsea and Westminster Hospital which houses the radio station (PRLog, 2009). Exterior photo of main entrance elevation (New London Architecture, 2005).

6.4.2 Chelsea and Westminster Hospital: Analysis of measured plans



Case Study No.3: The Chelsea and Westminster Hospital 2010

	Basement floor	Lwr grnd flr	Grnd floor	First floor	Second floor	Third floor	Fourth floor	Fifth floor	Total area/sqm	% of Total
Plant	3431.4	1753.6	587.56	644.72	3921.12	655.52	655.56	1664.68	13314.16	17.2%
Comms	1308.96	1197.72	2289.36	1470.56	1246.84	854.96	1549.7	1370.78	11288.88	14.6%
Total/sqm	4740.36	2951.32	2876.92	2115.28	5167.96	1510.48	2205.26	3035.46	24603.04	31.8%
Morgue		435							435	
Support		7758.46							7758.46	
									0	
A&E			838.16						838.16	
OPD			814.48						814.48	
Ante-natal			792.92						792.92	
Paeds OPD			828.72						828.72	
Support			1480.96						1480.96	
Pharmacy			531.56						531.56	
Administration			303.6						303.6	
Rehab			1784.52						1784.52	
Day case			1417.64						1417.64	
LOF			41.76						41.76	
Retail			314.08						314.08	
									0	
Paeds ward				2048.44					2048.44	
Theatres				574.08					574.08	
OPD				4271.72					4271.72	
Imaging				963.64					963.64	
Dermatology				1204.8					1204.8	
									0	
Pathology					2725.88				2725.88	
Wards					2454.12				2454.12	
									0	
Maternity						3349.48			3349.48	
Wards						2831.04			2831.04	
Pathology						1949.24			1949.24	
									0	
Wards							6192		6192	
Pharmacy							1363.64		1363.64	
									0	
ICU								550.28	550.28	
Staff								280.8	280.8	
Day Theatre								156	156	
Day Ward								2343.24	2343.24	
Theatres								2077.32	2077.32	
Total area ex. Plant/Comms/sqm	0	8193.46	9148.4	9062.68	5180	8129.76	7555.64	5407.64	52677.58	68.2%
Total area/sqm	4740.36	11144.78	12025.32	11177.96	10347.96	9640.24	9760.9	8443.1	77280.62	
High tech	0	435	5720.64	2742.52	2725.88	5298.72	6192	5407.64	28522.4	36.9%
Wards, OPD, support	0	7758.46	3427.76	6320.16	2454.12	2831.04	1363.64	0	24155.18	31.3%
Plant/Comms.	4740.36	2951.32	2876.92	2115.28	5167.96	1510.48	2205.26	3035.46	24603.04	31.8%
Total/sqm	0	8193.46	9148.4	9062.68	5180	8129.76	7555.64	5407.64	52677.58	
high tech									28522.4	54.1%
low tech									24155.18	45.9%

Appendix F.35 The Chelsea and Westminster Hospital (2010): Charts highlighting quantitative measurement of technology against spatial functionalities.

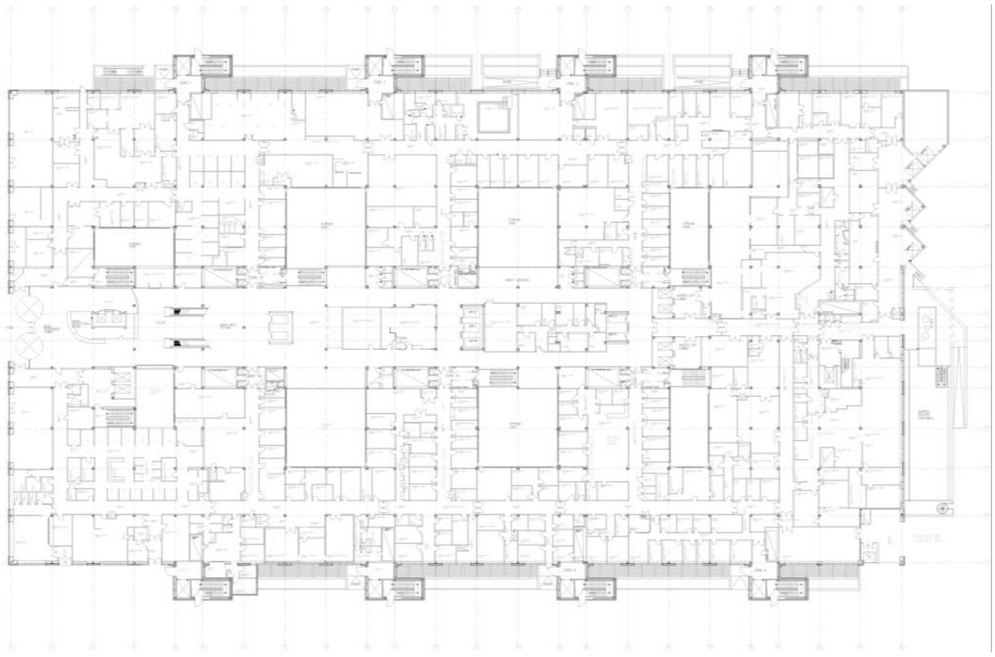
	% Low tech	% Plant comms	% High tech	% FM
2000	31.3	31.8	36.9	NA*
2010	31.3	31.8	36.9	NA*

Appendix F.36 2000-2010 including Plant/Comms. **(**NA* no FM facility as this is not a PFI hospital).

	% Low tech	% High tech
2000	45.9	54.1
2010	45.9	54.1

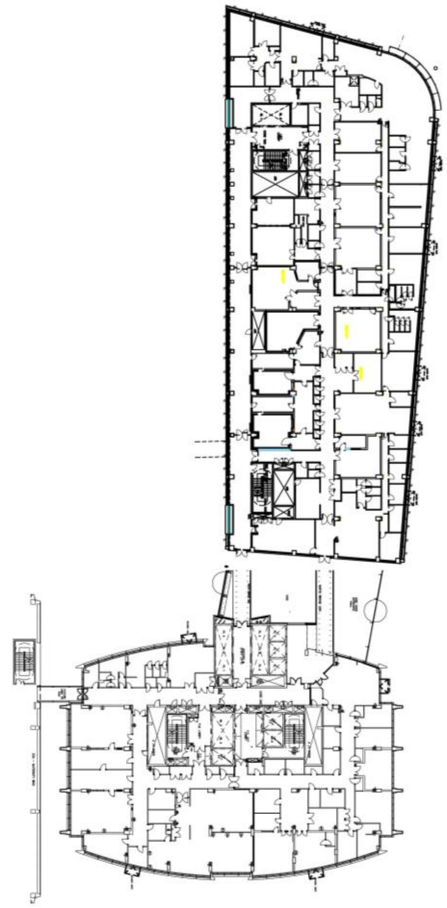
Appendix F.37 2000-2010 excluding Plant/Comms.

6.4.2 Chelsea and Westminster Hospital: Analysis of measured plans



Appendix F.38 2010, Typical floor plan, Chelsea & Westminster Hospital (Sheppard Robson Architects).

6.5.2 UCLH: Analysis of measured plans

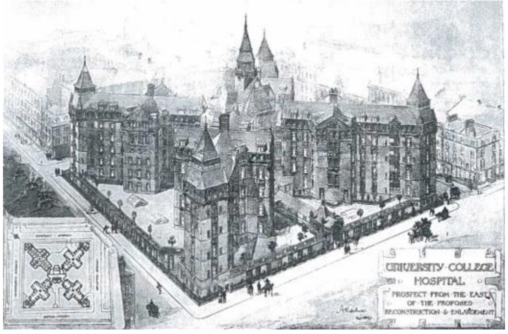


Appendix F.39 Plan of Level 2, UCLH, 2010 (UCLH Trust Facilities Offices).

6.5 Case Study No.4: UCLH

Functional Unit	Room Number	Size (m2)
A & E & Fracture Clinic		1188
Acute Assessment Unit		1392
Ambulatory Intervention		3505.2
Critical Care Facility		1412.9
CCU		254

Appendix F.40 Segment of UCLH Departmental Schedule of Accommodation (SOA), 2010 (UCLH Trust Facilities Offices).



Left: Appendix F.41 Perspective of UCH rebuilt 1897-1906 (Barry & Carruthers, 2005:125). **Right: Appendix F.41a** External view of UCLH by Llewellyn Davies Architects (2005).

6.5.2 UCLH: Analysis of measured plans

Case Study No.4: UCLH		
Areas	**Unit**	**RRV03**
Gross internal site floor area	m^2	76,249
Occupied floor area	m^2	72,416
NHS estate Occupied Floor Area	%	97.5
Site Heated Volume	m^3	190,623

Appendix F.42 Results of all measured plans: UCLH whereby RRV03 is UCLH excluding the new Maternity building (UCLH Trust Facilities Offices).

6.5.2 UCLH: Analysis of measured plans

Case Study No.4: UCLH						
Departmental Unit	**Total/sqm**	**%**	**high tech**		**low tech**	**Total/sqm**
A & E & Fracture Clinic	1187.9		1187.9			
Acute Assessment Unit	1392		1392			
Ambulatory Intervention	3505.2		3505.2			
Critical Care Facility	1412.9		1412.9			
CCU	254		254			
Operating Theatres	2197.7		2197.7			
Maples Refurbishment	768.1		768.1			
General Inpatients	970.8				970.8	
General Inpatients (Surgical)	1364.9				1364.9	
General Inpatients (Medical)	1330.3				1330.3	
Cardiology Beds	1113				1113	
Acute Renal Unit	395.3		395.3			
Infection Unit	1373.5		1373.5			
Outpatients	2252.4				2252.4	
Diagnostic Imaging	1496.9		1496.9			
Nuclear Medicine	1138		1138			
Radiopharmacy & High Dose Radiati	191.9		191.9			
Radiotherapy & Medical Physics Su	2141.5		2141.5			
Private Patients	2575.6		2575.6			
Therapies Unit	971.3		971.3			
Paediatrics	1390.8		1390.8			
Adolescents	1380.3		1380.3			
Haematology / Oncology	2750.8		2750.8			
Pharmacy Dispensary	156.1		156.1			
Pharmacy Support	423		423			
Discharge Lounge	114.7				114.7	
Metabolic Kitchen	26.6				26.6	
Surgical Applicances	52.6				52.6	
Sterile Services	662.6				662.6	
Ground Floor Podium	888.3				888.3	
Place of Worship	158.3				158.3	
Mortuary	585.3		585.3			
Staff Restaurant	465				465	
Total/sqm ex.Plant/Comms/FM	**37087.6**		**27688.1**		**9399.5**	**37087.6**
			74.7%		25.3%	100.0%
FM	1655					
UAS	3833					
Total/sqm ex. Plant/Comms	**42575.6**					
As built (FROM uclh RECENT CALCULATIONS)						
Full PFI	76249					
Maternity	11348					
Acute hospital Total/sqm	**64901.00**					
Plant/Comms/sqm	**22325.40**					

6.5.2 UCLH: Analysis of measured plans

Wards, OPD,support	9,399.50	14.5%		
High tech	27,688.10	42.6%		
Plant/Comms/UAS	26,158.40	40.3%		
FM	1,655.00	2.6%		
Total	**64,901.00**	**100.0%**		
Wards, OPD,support	9,399.50	25.3%		
High tech	27,688.10	74.7%		
Total	**37,087.60**	**100.0%**		

Appendix F.43 Results of all measured plans: UCLH

	% Low tech	% Plant comms	% High tech	% FM
2005	14.5	40.3	42.6	2.6
2010	14.5	40.3	42.6	2.6

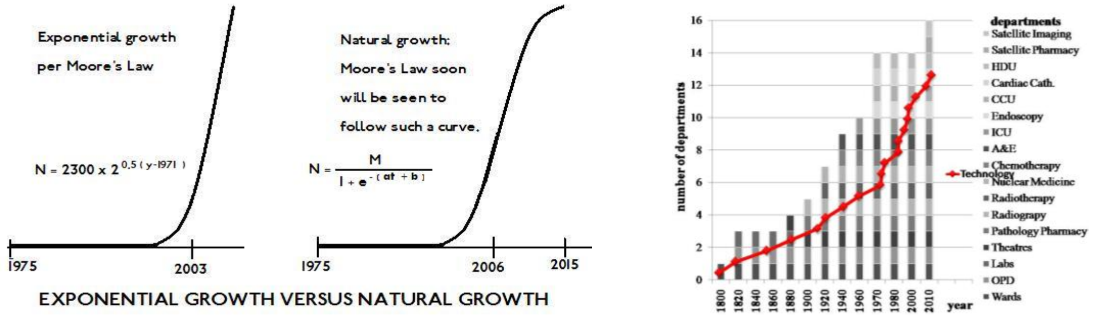
Appendix F.44 1832-2010 including Plant/Comms..

	% Low tech	% High tech
2005	25.3	74.7
2010	25.3	74.7

Appendix F.451832-2010 excluding Plant/Comms..

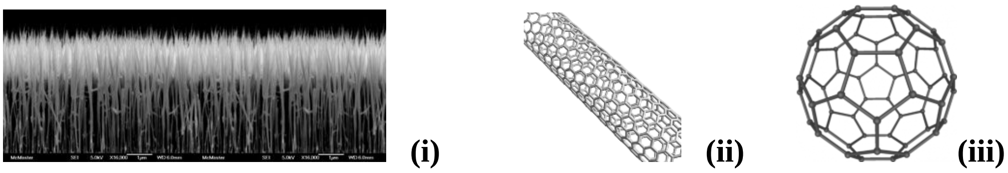
Appendix G

7.0 Introduction



Appendix G.1 Moore's Law: progression of computer technology v's Chapter 5's rate of hospital space growth.

7.1 Defining ET principles: All about scale


(i) (ii) (iii)

Appendix G.2 Structures of nanotechnology: (i) Nanowires; (ii) Carbon nanotubes; (iii) Bucky balls.

Nanotechnology

Discrepancies surround the definition for nanotechnology. For example, in 2012, nanotechnology is commonly referred to but is scientifically:

> Application of scientific knowledge to manipulate and control matter in the nanoscale in order to make use of size and structure dependent properties and phenomena, as distinct from those associated with individual atoms or molecules or with bulk materials (Mueller et. al., 2012:276).

However, biotechnologist Dr. Raj Bawa disagrees:

> Often used, yet clearly wrong, definition of nanotechnology is that proposed by the U.S. National Nanotechnology Initiative (NNI). It limits nanotechnology to 'dimensions of roughly 1 to 100 nanometers' Government agencies such as the FDA and the US Patent & Trademark Office (PTO) continue to use a similar definition based on a scale of less than 100 nm (Bawa, 2008:5).

Clarity was sought for a universal set of standards to be established for nanotechnology. In 2010, The International Standardization Organization (ISO) Technical Specifications defined nanotechnology as:

> The application of scientific knowledge to control and utilize matter in the nanoscale, where properties and phenomena related to size or structure can emerge (ISO/TS 80004-1:2010).

The ISO continues to specify:

> Nanomaterials are split into ‘nano-objects’...and we use therefore the frequently applied term ‘engineered nanomaterial’; a term representing intentionally produced materials that have one or more dimensions on a scale between about 1 and 100 nm (Hischier & Tobias, 2012:271) (see Figure 7.1).

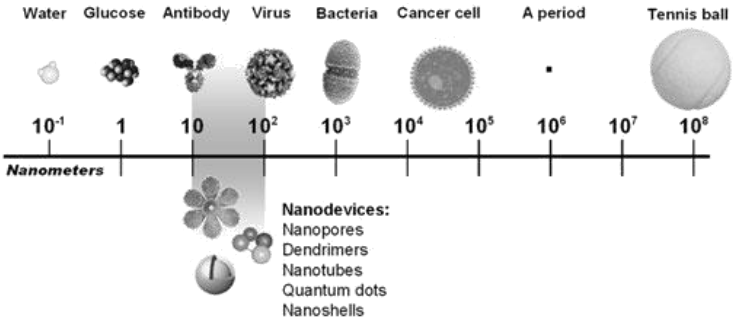


Figure 7.1 Diagram representing the scale of nanotechnology from a medical perspective.

Generally, nanotechnology is the application of engineering and science where ‘at least one dimension is on the nanometer scale (one-billionth of a meter)’ (Sahoo et. al., 2007:20). As Dr. Jerome Glen argues, nanotechnology ‘is more of an approach to engineering than a science’ itself (Glenn, 2006:129). Including terminologies such as ‘nanoscale’ and ‘nanomaterials’:

> Nanotechnology has more to do with the investigation of novel properties...and of the ability to manipulate and artificially construct structures at that scale (Kostoff et. al., 2007:1734).

Already a multi-billion pound world-wide market, where commercial growth is estimated to reach £700 billion by 2010 (HCSTC, 2004:5),

> Nanotechnology has been explored for creating lighter and stronger materials,...and ...is already used in hundreds of products across various industries such as electronics, healthcare, chemicals, cosmetics, materials, and energy (Morose, 2010:285).

Appendix G.3 Definitions and background to nanotechnology.

7.1.1 Analysis: Micro v nano

Analysis: Micro v nano

Nanotechnology works from the bottom up (positive engineering) as opposed to microtechnology which is negatively engineered from the top down (see Table A7.1).

> The bottom-up approach involves physically manipulating small numbers of the basic building blocks, either individual atoms or more complex molecules, into structures typically using minute probes (Horton & Khan, 2006:42).

While ‘the predicted benefits of nanotechnology are much hyped’ (The Lancet, 2003:673), nanotechnology’s current capability:

> Is limited to low-volume, high-value applications...but the range of bottom-up techniques and the areas of application are growing rapidly (Horton & Khan, 2006:43).

MEMS top-down approach is already an established chip-technology which is expected to be the preferred fabrication method for some time as ‘the application of microtechnology is generally far closer to the market and to a large extent it is already with us’ (HCSTC, 2004:7). However:

> Lord Salisbury seems to believe that the microtechnology industry will evolve into a nanotechnology industry (Caton, 2004:Column446WH).

One certainty is that microtechnology cannot develop into nanotechnology. The production processes are completely different.

Technology Scale	Fabrication Approach	Process
micro	top-down	Lithographic chip-technology - sculpts away
nano	bottom-up	builds one atom at a time – currently time consuming and expensive (see Appendix G.4 for nanotechnology structures).

Table A7.1 Tabled analysis of microtechnology v nanotechnology.

Appendix G. 4 Analysis of microtechnology v nanotechnology.

7.1.1 Analysis: Micro v nano

	Microtechnology	Nanotechnology
Definition	MEMS are microscopic devices made from silicon	Research and manufacturing at the atomic level (1nm-100nm)
Composition	One millionth of a meter (1µm). Uses photolithography. At one micrometer, 1000µms.	Nanotechnology works from bottom up at 0.1nm to 100nm. 1 billionth of a meter(1nm)
Advantages	Most of the equipment required to work at this scale and the nano scale are at this level.	Capable of manipulating or creating new matter. Lighter materials with greater strength. Can detect diseases in the bloodstream. Generate light and energy, and purify water.
Disadvantages	Lithography is extremely accurate and currently has some disadvantages.	Hazards with nanopartices unknown, Environmental dangers & toxicological effects
Current status	Restricted funding for research. MEMS already exists in the market	Predominantly in research phase. UK lags behind rest of world.

Appendix G.5 Analytical table of collated information for microtechnology and nanotechnology.

7.1.2 Degrees of certainty: Driving factors for technology success

(i) Funding & finance: Findings amounted to few scientists mentioning the significance of money to the success of R&D and manufacturing. However, as author Trevor Williams accurately points out:

> New inventions do not in themselves suffice to bring about technological progress; the availability of capital to exploit them has always been a major consideration (Williams, 1978:48).

On this basis, three examples highlight the issues facing current medical ET progression.

First, as long as funding remains plentiful, nanotechnology is suggested to supersede microtechnology but since commencing this research a major global economic recession has developed. However, Kurzweil puts forward his argument (see Figure A7.2):

> The underlying exponential growth in the economy is a far more powerful force than periodic recessions. Most important, recessions, including depressions, represent only temporary deviations from the underlying curve (Kurzweil, 2006:99).

From a UK perspective, Dr. Iddon, in addressing the House of Commons, argues the likelihood for near-future technology:

> Will probably be in microtechnology rather than nanotechnology (Hansard, 2004:Column 449WH).

Therefore, this thesis does not consider the current depression negatively in the long-term achievements of future medical ET progression.

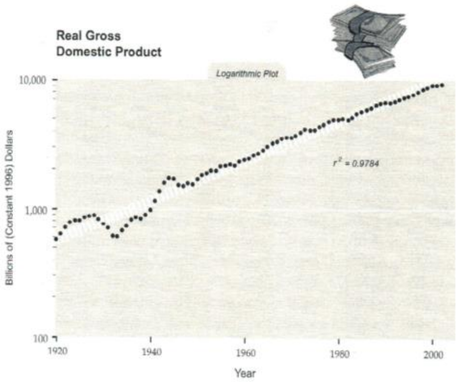


Figure A7.2 Graph of economic growth despite recessions (Kurzweil, 2006:98).

Second, while computation costs have drastically been reduced over recent decades, large medical equipment continues to be expensive. Briefly, the medical industry hasn’t been able to apply similar economies of scale associated with non-medical technologies due to the small volumes of saleable units (Kessler, 2007:119). This brings the thesis to ask: Will manufacturers want to invest in non-profitable medical ET? Computer expert Andy Kessler believes that affordability will be achieved ‘so much of the process uses silicon’ and ‘silicon means smaller, cheaper, faster, better’ (Kessler, 2007:183).

Third, staff salaries are the largest expense of any healthcare system and any ET that can potentially reduce running costs is worthy of development. For example, Japan has identified a shortage of nursing staff to care for its growing elderly population. Their response is a commitment to robotic development to assist with increasing medical demands (see section 7.3). However, ET in the UK are not as advanced as competing nations (US, Germany and Korea) as British businesses do not seem to be interested in a technology that's too difficult to understand and needs many qualified scientists[1] (Kostoff et. al., 2007:1743). In 2007, few nanotechnology courses existed in British universities questioning how the future nanotechnology industry would be staffed without trained graduates. By 2012, this situation has been totally reversed with numerous courses available at British universities. Educational investment needs to continue and grow for the future of ET to succeed.

(ii) Time: From concept to completion, it takes many years to deliver a consumable product. Time is a costly business for medical technology manufacturers which often render a technology non-viable if its timescales are commercially unprofitable. For example, the realisation of nanorobots depends on the speed at which the following processes need to be undertaken:

> First, theoretical scaling studies are used to assess basic concept feasibility. These initial studies would then be followed by more detailed computational simulations of specific nanorobot components and assemblies,...experimental efforts may progress from component fabrication and testing, to component assembly, and finally to prototypes and mass manufacture, ultimately leading to clinical trials (Freitas Jr., 2005:19).

As clinical trials take many years to receive Food and Drug Administration (FDA, US) or Medicines and Healthcare products Regulatory Agency (MHRA,UK) approval, the success of nanotechnology will depend upon the reduction of timescales within its numerous processes.

(iii) The consumer: Never underestimate the power of the consumer as even the best current technology is not being maximised by clinicians due to their preference to utilise

---

[1] Only Unilevel and GlaxoSmithKline seem to be interested but these are US organisations.

what they operate and know already. For example, in the US, older technology continues to be used based on insurance companies' payments. In the UK, the use of older equipment is directly driven by NHS technology budgets. Therefore, for ET to succeed they need to be affordable, easy to use and accessible.

(iv) Hazards & ethics: Little emerged from literature to confirm the hazards of ET (Fleischer et. al., 2005:1114). Concerns about the extent of their dangers are however expressed. For example, the hazards of nano-particles i.e. 'nanotubes' and 'quantum dots' may cause health and environmental problems (Morose, 2010:285).

> For example, nanomaterials,...could theoretically behave like quartz or asbestos particles and result in similar damaging effects on the respiratory system (The Lancet, 2007:1142)

Immediate research is therefore necessary before more time, money and resources are wasted in developing a potentially harmful technology. This is supported by The Royal Society's recommendations:

> Until research has been undertaken and published in the peer-reviewed literature, it is not possible to evaluate the potential environmental impact of nanoparticles...we recommend that the release of manufactured nanoparticles and nanotubes into the environment be avoided as far as possible (The Royal Society & The Royal Academy of Engineering, 2004:50).

For medical technologies, the stakes are significantly higher as our biological well-being may be at risk. As Prof. Anthony Seaton, Aberdeen University highlights: 'Toxicological effects are poorly understood...exposure is likely to occur through inhalation, ingestion and skin absorption' but as 'no current specific medical evaluation protocols exist for exposure to nanoparticles' (Hoyt & Mason, 2007:10), consumable use of nanotechnology will be delayed due to the lack of precautionary research. All of these hazards do not dilute the ethical issues attached to ET. Both factors need to be researched adding further time and costs to technology production and success.

Appendix G.6 Degrees of certainty: Driving factors for technology success.

7.2.1 Biotechnology future trends

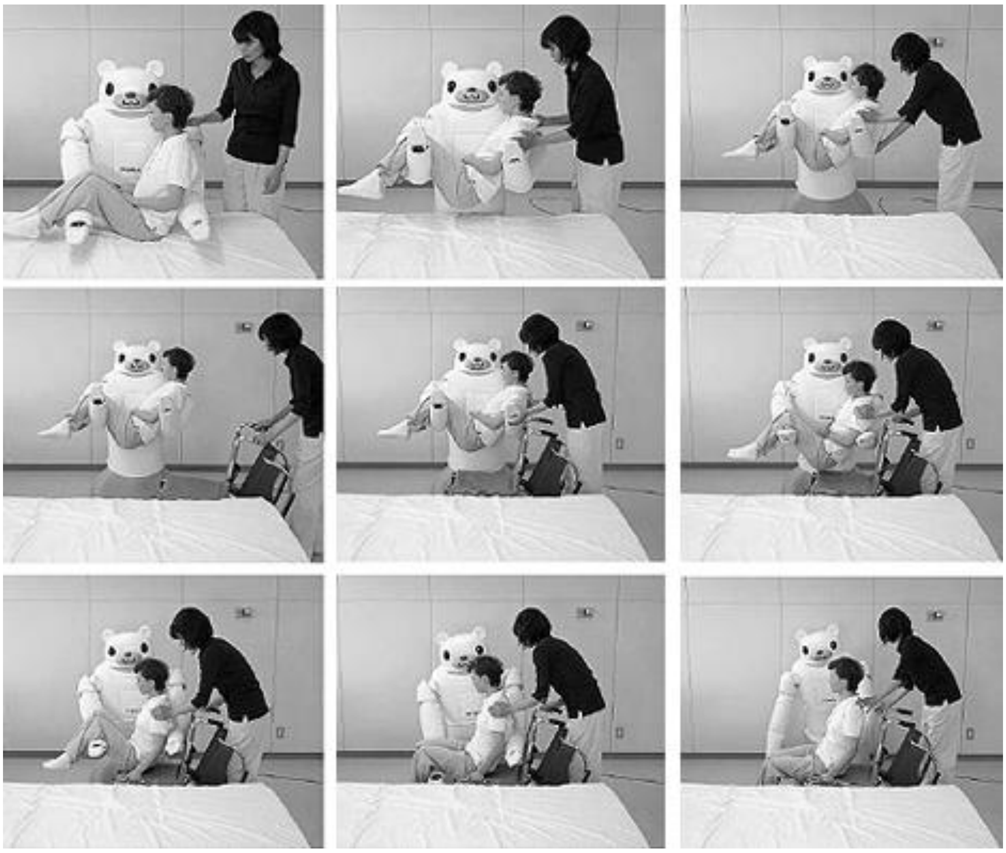
Appendix G.7 The Hemochron Junior point-of-care whole blood coagulation testing device (International Technidyne Corporation). The handheld device (left) employs single-use sample/reagent cuvettes (right) to measure activated clotting time, partial thromboplastin time, prothrombin time. Quality control and test results can be downloaded via serial and ethernet ports (Willmott & Arrowsmith, 2010:159-60).

7.3 Robotics: Definitions and background

Appendix G.8 World-first heart op by a robot arm, Dr Andre Ng, Leicester Hosptial (Radnedge, 2010:23).

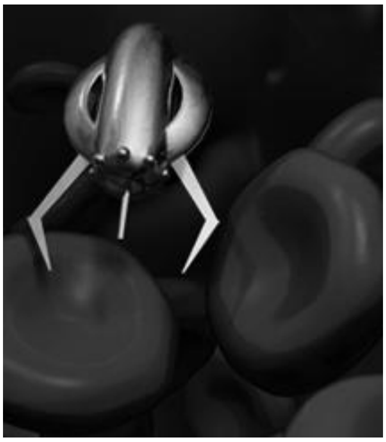
Appendix G.9 da vinci surgical robot [Online]. Available at: http://robocatz.com/daVinci-surgical.htm (Accessed: 14th August 2013).

7.3 Robotics: Definitions and background



Appendix G.10 RIBA human assisted robot, developed by researchers at Japan's Institute of Physical and Chemical Research (RIKEN) and Tokai Rubber Industries, Ltd. (TRI). Designed primarily to assist nurses by lifting patients in and out of their beds and wheelchairs (as well as on and off the toilet), the 180-kilogram (400-lb) robot can safely pick up and carry people weighing as much as 61 kilograms (135 lbs) [Online]. Available at: http://pinktentacle.com/2009/08/riba-robot-nurse-bear/ (Accessed: 1st September 2012).

7.3.1 Clinical robotic future trends



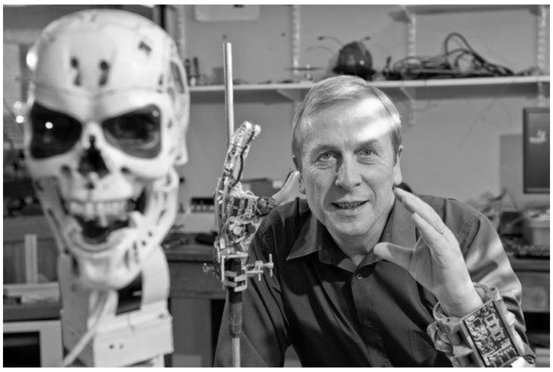
Appendix G.11 An image of anticipated nanorobot [Online]. Available at: http://metallurgyfordummies.com/what-is-nanotechnology/nanorobot-1/ (Accessed: 9th March 2013).

7.3.1 Clinical robotic future trends

Appendix G.12 Humans assisted robots: u-Bot5, University of Massachusetts [Online]. Available at: http://www.geekologie.com/2008/04/ubot-5-robot-designed-to-help.php (Accessed: 13th April 2008).

Appendix G.13 RP6 system consists of mobile device and work desk for clinicians [Online]. Available at: www.sciencedaily.com/releases/2005/05/050519083715.htm (Accessed: 11th May 2009).

7.4 Cyborgization: Definitions and background



'I want to do something with my life; I want to be a cyborg'

Appendix G.14 Left: Warwick, K. (2007) Upgrading Humans - Technical Realities and New Morals, *The Jounral of Geoethical Nanotechnology*, p.3 [Online]. Available at: http://www.terasemjournals.org/GNJournal/GN0204/kw3.html (Accessed: 7th July 2013).
Right: Flintoff, J. (2011) Weirdly useful science of the amateur lab rats, *The Sunday Times*, 27th February [Online]. Available at: http://www.thesundaytimes.co.uk/sto/newsreview/features/article563056.ece (Accessed: 7th July 2013).

7.4.2 Spatial analysis for future cyborgization in hospitals

Appendix G.15 Advanced Multimodality Image Guided Operating (AMIGO) Suite, at the National Center for Image-Guided Therapy (NCIGT) at the Brigham and Women's Hospital (BWH) and Harvard Medical School [Online]. Available at: http://www.ncigt.org/pages/File:AMIGO2011-03.png (Accessed: 4th July 2013).

Appendix H

8.2 Discussion of findings for future urban acute hospital space

scale	ET type	UAT Department				
		A&E	**OT**	**Imaging**	**Pharmacy**	**Pathology**
Equipment size changes	**Biotechnology**	1. Custom made drugs - New equipment added. 2. Drug delivery systems – no change to equipment. 3.POCT/LOC/ LIC – to become smaller. 4. *ME –More equipment added.	1. Custom made drugs – *NA. 2. Drug delivery systems – no change to equipment. 3.POCT/LOC /LIC – to become smaller. 4. ME – More equipment added.	1. Custom made drugs - NA. 2. Drug delivery systems – no change to equipment. 3. POCT/ LOC/LIC– to become smaller. 4. ME – NA	1. Custom made drugs – New & increased numbers of equipment. 2. Drug delivery systems – More equipment needed. 3. POCT/LOC /LIC – to become smaller. 4. ME – NA	1. Custom made drugs - NA. 2. Drug delivery systems – no change. 3. POCT/LOC /LIC – to become smaller. 4. ME – More equipment added.
	Robotics	1. Non-clinical – new additions. 2. Clinical robots – smaller surgical & nano robots. More telesurgery. 3. Human assisted robots – new presence in department.	1. Non-clinical – new additions. 2. Clinical robots – smaller surgical & nano robots. More telesurgery. 3. Human assisted robots added.	1. Non-clinical – new additions. 2. Clinical robots – smaller surgical & nano robots. More telesurgery. 3. Human assisted robots – new presence in department.	1. Non-clinical – new additions. 2. Clinical robots – NA. 3. Human assisted robots – NA.	1. Non-clinical – new additions. 2. Clinical robots – NA. 3. Human assisted robots – NA.
	Cyborgization	1. Bionics & AI – new equipment added.	1. Bionics & AI – new equipment added.	1. Bionics & AI – new equipment added.	1. Bionics & AI – new equipment added.	1. Bionics & AI – new equipment added.

***not applicable (NA)** ***molecular engineering (ME)**

Appendix H.1 Table of spatial implications of ET at different medical planning scales.

scale	type	UAT Department				
		A&E	**OT**	**Imaging**	**Pharmacy**	**Pathology**
1:200 spatial impact	**Biotechnology**	1. Reduced assesment, observation and treatment spaces. 2. No changes. 3. Less space required for POCT/LOC/LIC equipment. New rooms to watch patient signals. New LIC area required. LIC - to reduce A&E assessment. Dispersed pockets of space required. 4. Larger trauma bays.	1.* NSI 2. NSI 3. Dispersed pockets of space required. 4. More OT rooms needed for demand. No increase to space in OT rooms.	1. NA 2. NSI 3. Dispersed pockets of space required. Reduced space required in imaging rooms. 4. NA	1. Aseptic suite to increase in size. Larger lab spaces required for bigger equipment that produce larger batch samples. 2. No. of clinical spaces and rooms to increase i.e. storage, offices, labs. 3. NA 4. NA	1. NA 2. NA 3. LOC requires smaller space - Pathology spaces reduced. 4. New rooms for therapeutic cloning, tissue & organ engineering 5. General - New rooms for equipment, storage, offices & procedures.
	Robotics	1. Storage space needed. 2. Larger trauma spaces. 3. No spatial change. 4. General – increased space for storage.	1. Storage space needed. 2. Smaller space required in OTs. 3. No spatial change. 4. General – increased space for storage.	1. Storage space needed. 2. Access to 3D scanners – new adjacencies. 3. No spatial change. 4. General – more space for storage.	1. Storage space needed. 2. New space for equipment as demand increases. 3. NA. 4. General – NA.	1. Storage space needed. 2. NA. 3. NA. 4. General – NA.
	Cyborgization	1. Trauma bays increased for complex surgery. New rooms added.	1. Larger neurological OT rooms added. More rooms required for increased demand.	1. Additional rooms adjacent to OT required.	1. No spatial change.	1. New spaces required for new ME related services.

***no spatial impact (NSI)**
***not applicable (NA)**

***molecular engineering (ME)**

Appendix H.2 Table of 1:200 spatial implications of ET.

scale	ET type	UAT Department				
		A&E	**OT**	**Imaging**	**Pharmacy**	**Pathology**
1:500 impact	**Biotechnology**	1. Reduced EAU leaves 1:500 area smaller 2. No impact from POCT pockets of space	1. More available procedures will increase department size.	1. NA	1. Larger department size.	1. Larger department size. Relocated nearer to clinical teams
	Robotics	1. Larger Trauma Suite increase size of department	1. Option 1 -Smaller multiple OT rooms will slightly increase OT 2. Option 2 - Larger OT/Imaging suites will greatly increase department size	1. Change in location of Main Imaging and new dedicated UAT Imaging suite.	1. Larger department size.	1. Larger department size.
	Cyborgization	1. Larger Trauma Suite increases department size	1. Option 2 - Larger OT/Imaging suites, department increase in size	1. Change in location of Main Imaging and new dedicated UAT Imaging suite.	1. NSI	1. Larger department size. Relocated nearer to clinical teams
Spatial Impact		A&E location to remain. Size to grow initally but will stay as ET progress.	OT to grow in size, either slightly or substantially. OT to remain in same location.	Imaging to be subdivided. Spatial increases when relocated.	Department to grow in size. No 1:500 relocation necessary.	Larger department size and 1:500 relocation to be adjacent to OT/Imaging
Medical Planning Impact		1. 1:500 medical planning adjacencies and flows altered for A&E, OT, Imaging, Pharmacy, Pathology and Bio. Eng. 2. 1:500 relocations for Pathology, Imaging and Bio. Eng. 3. Decentralisation of laboratory services 4. Planning problems for column structure in A&E 5. Increased size of OT floor to pressurise hospital typology				
1:1000 Spatial Impact		1. A&E and Pharmacy to externally expand at ground floor levels. 2. Creation of super floor of OT, Imaging, Pathology Bio. Eng.				

***no spatial impact (NSI)** ***molecular engineering (ME)**
***not applicable (NA)**

Appendix H.3 Table of 1:500/1000 spatial implications from ET.

Bibliography

Aalto, A. (1940) The Humanizing of Architecture. Functionalsim Must Take the Human Point of View to Achieve its Full Effectiveness, *The Technology Review*, November, pp.14-6.

ABC News (2011) Scientist Stephanie Palmer works on new DNA sequencing machines, ABC News, 4th May 2011 [Online]. Available at: http://www.abc.net.au/news/2009-07-21/scientist-stephanie-palmer-works-on-new-dna/1361778 (Accessed: 18th July 2013).

Adams, M. (2011) Ground-breaking technique to harvest body tissue ends Liz Coveney's pain, *Daily Echo*. Tuesday 27th September. Available at: http://www.dailyecho.co.uk/news/9273653.Woman_has_knee_re_grown_in_pioneering_treatment/?ref=rss (Accessed: 12th January 2012).

Allen, J. (2010) Reboot of the robots, *Wired,* October, pp.133-9.

Allen, S. (2001) Mat Urbanism, pp.118-26 in Sarkis, H. (ed.) (2001) *Case: Le Corbusier's Venice Hospital and the Mat Building Revival*, Prestel.

Anam, K. and Al-Jumaily, A. (2012) Active Exoskeleton Control Systems: State of the Art, *Procedia Engineering*, vol. 41, pp.988-94.

Ancell, H. and Crump, H. (2007) Hospital robots spark design row; Architects: Keppie Design, *Building Design*, no. 1778, 6th July, p.3.

Andersson, H. and van bed Berg, A. (2004) Microtechnologies and nanotechnologies for single-cell analysis, *Current Opinion in Biotechnology*, vol. 15, issue 1, pp.44-9.

Ansoff, I. (1965) *Corporate Strategy*, Mc Graw-Hill, New York.

Architectural Record (1970) Northwick Park Hospital: where only growth and change are constant, *Architectural Record*, December, pp.101-4.

Aris Mantzoros S.A. (2012) *Opti R Blood gas and electrolyte analyzer* [Online]. Available at: http://www.mantzoros.gr/en/products/blood-gas/BLOOD-GAS-AND-ELECTROLYTE-ANALYZERS/Opti-R (Accessed: 30th September: 2012).

Arnold, D. (2004) Hospital design 'too inflexible', *Building Design,* no. 1631, 2004 June 25, p.7 quote from Future Healthcare Network (2004) *Getting the best out of future capital investment in health: A Future Healthcare Network Report*, NHS Confederation.

Aronowitz, J. (2007) Ethereal Fire: Antecedents of Radiology and Radiotherapy, *American Journal of Roentgenology*, vol. 188, issue 4, 1st April, pp.904-12.

Bardwell, P. (2007) Leading Change: The Academy of Architecture for Health Foundation Grants, *Health Environments Research & Design Journal*, vol. 1, issue 1, pp.22-4.

Barlow, J. and Köberle-Gaiser, M. (2008) The private finance initiative, project form and design innovation The UK's hospitals programme, *Research Policy*, vol. 37, issue 8, September, pp.1392-1402.

Barnett, J. (1966) Last works of Le Corbusier, *Architectural Record,* April, pp.187-94.

Barron, S. (1950) Development of the Electrocardiograph in great Britain, *British Medical Journal*, vol.1, issue 4655, 25th March, pp.720-5.

Barry, G. and Carruthers, L. (2005) *A History of Britain's Hospitals*, Book Guild Publishing.

Bawa, R. (2008) NanoBiotech 2008: Exploring global advances in nanomedicine, *Nanomedicine: Nanotechnology, Biology, and Medicine*, vol. 5, issue 1, pp.5-7.

Birchard, K. (1999) The science of haptics gets in touch with prosthetics, *The Lancet*, vol. 354, issue 9172, 3rd July, p.52.

Black, N. (2005) Rise and demise of the hospital: a reappraisal of nursing, *British Medical Journal*, vol. 331, 10th December, pp.1394-6.

Black, R., Fava, F., Mattei, N., Robert, V., Seala, S. & Verdiere, V. (2011) Case studies on the use of biotechnologies and on biosafety provisions in four African countries, *Journal of Biotechnology*, vol. 156, issue 4, 20th December, pp.370-81.

Black, R., Verdier, V., Fava, F., Mattei, N. and Robert, V. (2010) *Case Studies on the Use of the Green, White, Blue and Red Biotechnologies in Five African Countries: A Contribution to Discussion of Possible Future European Support for Biotechnology in Developing Countries*, European Consortium for Agricultural Research in the Tropics European Economic Interest Grouping (EEIG), European Commission.

Blackman, D. (2003) Prescription for progress A flexible approach is needed if healthcare facilities are to keep pace with developments in medical science, pp.15-6 in Rattenbury, K. (2003) Building Futures, *Building Design*, no. Supplement, November, pp.1-34.

Board, E. (1912) *Dr Jenner performing his first vaccination, on James Phipps, a boy of 8. May 14 1796*. Wellcome Library, London [Online]. Available at: http://wellcomeimages.org/indexplus/image/V0018142.html (Accessed: 1st May 2012).

Boon, W. & Moors, E. (2008) Exploring emerging technologies using metaphors - A study of orphan drugs and pharmacogenomics, *Social Science & Medicine*, vol. 66, issue 9, May, pp.1915-27.

Booth, R. (2000) Think tank accuses PFI of ‘off-the-shelf’ hospital design , *Architects’ Journal*, vol. 212, no. 9, 14th September, p.16.

Borriello, S.P. (1999) Science, medicine, and the future: Near patient microbiological tests, *British Medical Journal*, vol. 319, issue 7205, 31st July, pp.298-301.

Bradbury, J. (2000) Journey to the centre of the body, *The Lancet*, vol. 356, issue 9247, 16th December, p.2074.

Brandel, K. (1872) *Lupus vulgaris Tuberculosis*, Vite Vu [Online]. Available at: http://www.sfp.photographie.com/coll/coll-index.htm (Accessed: 6th January 2011).

Brinker, J. (2012) Imaging for Infected Cardiac Implantable Electronic Devices A New Trick for Your Pet, *Journal of the American College of Cardiology*, vol. 59, no. 18, 1st May, pp.1626-8.

Brunel, I. (1870) Life of Isambard Kingdom Brunel quoted in Weeks, J. (1963-4) Indeterminate Architecture, *Bartlett Society Transactions*, 1963-1964, vol. 2, pp.88.

Building Design (1979) Standardised hospital plans should not be compulsory, *Building Design*, no. 434, 23rd February, p.6.

Burtis, C. (1995) Technological Trends in Clinical Laboratory Science, *Clinical Biochemistry*, vol. 28, no. 3, June, pp.213-9.

Campbell, A. (2007) Can’t you tell I’m angry? ‘Mood’ dress shows a woman’s emotions, *Metro*, Tuesday 18th December, p.21.

Cardiac Science (2012) Burdick Atria 6100, *Cardiac Science* [Online]. Available at: http://www.cardiacscience.com/cardiology-products/ecg-devices/burdick-atria-6100-12lead-resting-ecg.php (Accessed: 13th May 2012).

Centre for the History of Medicine (2013) *A Broad Foundation: Milestones of Medical Eduction at Harvard, 1783-1900*, exhibit curated by Jack Eckert for Centre for the History of Medicine [Online]. Available at: https://www.countway.harvard.edu/chm/rarebooks/exhibits/broad_foundation/broad_foundation4.html (Accessed: 13th August2013).

Chan, V. (2006) Nanomedicine: An unresolved regulatory issue, *Regulatory Toxicology and Pharmacology*, vol. 46, issue 3, December, pp.218-24.

Christopher , J. (1982) NHS gets cruciform - a look at the government’s Nucleus system and at the private enterprise approach, *Building Design*, no. 589, 9th April, p.14-7.

Chung, S. (2006) Bladder tissue-engineering: a new practical solution?, *The Lancet*, vol.367, issue 9518, 15th April, pp.1215-6.

Clement, R., Bugler, K. and Oliver, C. (2011) Bionic prosthetic hands: A review of present technology and future aspirations, *The Surgeon*, *Journal of the Royal Colleges of Surgeons of Edinburgh and Ireland*, vol. 9, issue 6, December, pp.336-40.

Cole, J. (2006) Strategic Planning for Healthcare facilities in Wagenaar, C. (ed.) *The Architecture of Hospitals*, NIA Publishers, pp.356-61.

Colquhoun, A. (1966) Formal and functional interactions: a study of two late projects by Le Corbusier, *Architectural Design*, May, pp.221-34.

Colwell, R. (2002) Fulfilling the promise of biotechnology, *Biotechnology Advances*, vol. 20, issues 3-4, November, pp.215-28.

Combs, D. (2006) Startling technologies promise to transform medicine, *British Medical Journal*, vol. 333, issue 7582, 23rd December, pp.1308-11.

Connor, J. and Pope, F. (1999) A Shocking Business: The Technology and Practice of Electrotherapeutics in Canada, 1840s to 1940s, *Material History Review*, Spring, pp.60-70.

Copplestone, T. (1991) *Twentieth-Century World Architecture*, Brian Todd Publishing House Limited.

Corliss, J. (2002) A Salute to Antony van Leeuwenhoek of Delft, Most Versatile 17th Century Founding Father of Protistology, *Protist*, vol. 153, issue 2, June, pp.177-90.

Cottineau, C., Cocaud, J. and Jacob, J. (1998) The beginning of anesthesia, *Allerg Immunol (Paris),* Department d'Anesthesie-Reanimation Chirurgicale B., C.H.U., Angers, Frances, vol. 30, issue 5, May, pp.135-7.

Crawford, G. (2005) A Brief History of Bacteriology, *The Biomedical Scientist, The Institute of Biomedical Science,* March [Online]. Available at: http://www.ibms.org (Accessed: 12th March 2008).

Cui, K. (2005) Three concepts of cloning in human beings, *Reproductive BioMedicine*, vol. 11, issue1, July, pp.16-7.

Darzi, A. (2007) *Saw and Scalpels to Lasers and Robots – Advances in Surgery Clinical Case for Change: Report by Professor Sir Ara Darzi, National Advisor on Surgery*, Department of Health.

Davies, B. (2006) Essay: Medical robotics - a bright future, *The Lancet*, vol. 368, Supplement 1, December, pp. S53-4.

Davies, B. (2000) Quoted in, A review of robotics in surgery, *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, vol. 214, issue 1, pp.129-40 in Ponnusamy, K., Mohr, C. & Curet, M. (2011) Clinical Outcomes With Robotic Surgery, *Current Problems in Surgery*, vol. 48, issue 9, September, pp.577-656.

Department of Health (1992) Nucleus study packs, DOH.

Department of Health (2005) *Guidance on Equipment in NHS PFI Projects,* Department of Health.

Department of Health (2007) *Rebuilding The NHS - A new generation of healthcare facilities,* Crown copyright, produced by COI for DOH.

Department of Health Estates & Facilities Division (1992-2010) *Health Building Notes*, Vols. 00 02 - 57. London: The Stationery Office.

Department of Health Estates & Facilities Division (2001) *HBN 06 - Facilities for Diagnostic Imaging and interventional radiology,* The Stationery Office.

Department of Health Estates & Facilities Division (2004) *HBN 26 - Facilities for surgical procedures Volume 1*, The Stationery Office.

Department of Health Estates & Facilities Division (2005) *Schedules of Accommodation Version 3.0 August 2007, HBN 15 Facilities for pathology services (July 2005)*, London: The Stationery Office.

Department of Health Estates & Facilities Division (2006) *HBN 28 - Facilities for cardiac services*, The Stationery Office.

Department of Health Estates & Facilities Division (2007) *HBN10-02 Surgery: Day surgery facilities*, The Stationery Office.

Department of Health Estates & Facilities Division (2007) *Schedules of Accommodation Version 3.0 August 2007, HBN 14-01 'Pharmacy and radiopharmacy facilities' (August 2007),* London: The Stationery Office.

Department of Health Estates & Facilities Division (2007) *Schedules of Accommodation Version 3.0 August 2007, HBN 22 'Accident and emergency facilities for adults and children' (April 2005)*, London: The Stationery Office.

Department of Health (2009) *Research and development work relating to assistive technology 2008-9*, Presented to Parliament pursuant to section 22 of the Chronically Sick and Disabled Persons Act 1970, Department of Health.

Destenaves, B. & Thomas, F. (2000) New advances in pharmacogenomics, *Current Opinion in Chemical Biology*, vol. 4, issue 4, August, pp.440-4.

Diamond, S. (2006) *R & D Project B (01)16: Rethinking hospital design A research study commissioned by NHS Estates*, UK: Department of Health.

Dorozynski, A. (1998) Robot helps perform open heart surgery, *British Medical Journal*, vol. 316, issue 7146, 6th June, p.1696.

Drexler, E. (1987) *Engines of Creation: The Coming Era of Nanotechnology*, Anchor.

ECRI Institute (2009) Top 10 Hospital Technology issues: C-suite Watch List for 2009 and Beyond, ECRI Institute.

Edwards, N. and Harrison, A. (1999) Planning hospitals with limited evidence: a research and policy problem, *British Medical Journal*, vol.319, issue 7221, 20th November, pp.1361-3.

Enajarvi, E. (1929) Interview with Alvar Aalto. Translated by Juhani Pallasmaa. *Tulenkantajat*, no.3, p.37 in Reed, P. (ed.) (1998) *Alvar Aalto Between Humanism and Materialism*, The Museum of Modern Art, Thames and Hudson, p.34.

Engel, E., Michiardi, A., Navarro, M., Lacroix, D. and Planell, J. (2008) Nanotechnology in regenerative medicine: the materials side, *Trends in Biotechnology*, vol. 26, issue 1, January, pp.39-47.

Euchiasmus (2012) NHS hospital to deploy clinical portal to improve workflow, *hospitalmanagement.net* [Online]. Available at: http://www.hospitalmanagement.net/news/newsnhs-hospital-to-deploy-new-clinical-portal-to-improve-clinician-workflow (Accessed: 18th August 2013).

Fasoli, S., Krebs, H., Stein, J., Frontera, W., Hughes, R. and Hogan, N. (2004) Robotic Therapy for Chronic Motor Impairments After Stroke: Follow-Up Results, *Archives of Physical Medicine and Rehabilitation*, vol. 85, issue 7, July, pp.1106-11.

Felder, R. (2003) Medical Automation - A Technologically Enhanced Work Environment to Reduce the Burden of Care on Nursing Staff and a Solution to the Health Care Cost Crisis, *Nursing Outlook*, vol. 51, issue 3, May/June, pp.S5-10.

Fermann, G. and Suyama, J. (2002) Point of care testing in the emergency department, *The Journal of Emergency Medicine*, vol. 22, isse 4, May, pp.393-404.

Feynman, R. (1960) There’s Plenty of Room at the Bottom An invitation to Enter a New Field of Physics, *Engineering and Science*, vol. 23, issue 5, February, pp.22-36.

Fisch, C. (2000) Centennial of the String Galvanometer and the Electrocardiogram, *Journal of American College of Cardiology*, vol.36, issue 6, 15th November, pp.1737-45.

Fleischer, T., Decker, M. and Fiedeler, U. (2005) Assessing emerging technologies - Methodological challenges and the case of nanotechnologies, *Technological Forecasting & Social Change*, vol. 72, issue 9, November, pp.1112-21.

Flintoff, J. (2011) Weirdly useful science of the amateur lab rats, *The Sunday Times*, 27th February [Online]. Available at: http://www.thesundaytimes.co.uk/sto/newsreview/features/article563056.ece

(Accessed: 7th July 2013).

Foster, W. and Pinniger, J. (1963) History of Pathology at St. Thomas's Hospital London, *Medical History*, vol. 7, issue 4, October, pp.330-47.

Foucault, M. (1963) *The Birth of the Clinic*, Presses Universitaires de France.

Foucault, M. (1989), *The Birth of the Clinic*, Routledge.

Francis, S., Glanville, R., Noble, A., and Scher, P. (1999) *50 Years of Ideas in health care buildings*, The Nuffield Trust.

Freitas Jr., R. (2003) *Nanomedicine, Volume IIA: Biocompatibility*, Landes Bioscience.

Freitas Jr., R. (2005) Current status of Nanomedicine and Medical Nanorobotics, *Journal of Computational and Theoretical Nanoscience*, vol.2, issue 1, pp.1-25.

Freitas, Jr., R. (2005) Nanotechnology, nanomedicine and nanosurgery. *International Journal of Surgery*, vol. 3, issue 4, pp.243-6.

Freitas Jr., R. (2005) What is nanomedicine? *Disease-a month,* vol. 51, issue 6, June, pp.325-41.

Freitas Jr., R. (2005) What is nanomedicine? *Nanomedicine: Nanotechnology, Biology and Medicine*, vol. 1, issue 1, March, pp.2-9.

Friesen, G. (1961) Mechanization and hospital design, *Architectural Design*, January, 1961, pp.7-9.

Furneaux Jordan, R. (1991) *Western Architecture A Concise History*, Thames and Hudson Ltd.

Future Healthcare Network (2004) *Getting the best out of future capital investment in health: A Future Healthcare Network Report*, NHS Confederation.

Gates, C. (2005) Hospitals may only last five years...Teachers must be given more say in school design, *Building Design*, no. 1679, 24th June, p.7.

Gibson, I. (2004) *Nanotechnology, House of Commons debate, Westminster Hall,* House of Commons Hansard Debates for 24the June: Column 439WH [Online].

Available at:

http://www.publications.parliament.uk/pa/cm200304/cmhansrd/cm040624/hallindx/40624-x.htm (Accessed: 19th July 2008).

Gilbert, W. (1998) quotation in Kaku, M. (1998) *Visions How Science Will Revolutionize the Twenty-First Century*, Oxford University Press, p.143.

Glenn, J. (2006) Nanotechnology: Future military environmental health considerations, *Technological Forecasting & Social Change*, vol. 73, issue 2, pp.128-37.

Godet, M. (1991) *From Anticipation to Action*, UNESCO, Paris.

Goldman, S. (2003) Emergency radiology as a sub-specialty has come of age, *European Journal of Radiology*, vol. 50, issue 1, April, pp.3-4.

Gorski, H. (2003) *Remains of the Kos Asclepieion* [Online]. Available at://en.wikipedia.org/wiki/File:Kos_Asklepeion.jpg (Accessed: 18th August 2009).

Gossel, P. and Leuthauser, G. (1991) *Architecture in the Twentieth Century*, Taschen.

Gower, R. (2011) *Strategic review: the process of strategy formulation in complex organisations*, Gower Publishing Limited.

Gray, C. (ed.) (1995) *The Cyborg Handbook*, Routledge, London.

Griffin, R. & Roughan, M. (2006) An open relationship, *Hospital development*, vol. 37, issue 3, March, pp.14-7.

Grzybowski, A. and Pietrzak, K. (2012) From patient to discoverer - Niels Ryberg Finsen (1860-1904) - the founder of phototherapy in dermatology, *Clinics in Dermatology*, vol. 30, issue 4, July-August, pp.451-5.

Hansen, J. (1974) *The Billings Microscope Collection*, Armed Forces Institute of Pathology, Washington.

Henly, R. (2004) Moore's Law - Past, Present, ...Future?, *HAL-PC Magazine*, March [Online]. Available at:

http://users.hal-pc.org/~slcweb2/0MonthlyPresent/0403MooreLaw/0MooreLaw.html (Accessed: 27th February 2009).

Hessenbruch, A. (2002) A brief history of x-rays, *Endeavour*, vol. 26, issue 4, 1st December, pp.137-41.

Higginbotham, P. (2010) *The MAB Land Ambulance Service* [Online]. Available at: http://www.workhouses.org.uk/MAB-Ambulances/ (Accessed: 3rd April 2010).

Hignett, S., Lu, J. & Morgan, K. (2007) *R&D Project B(02)13: Empirical review of NHS estates ergonomic drawings for the DH Estates and Facilities Division*, Crown copyright.

Hillman, K. (1999) The Changing role of acute-care hospitals, *The Medical Journal of Australia*, vol. 170, issue 7, 5th April, pp.325-8 [Online]. Available at: http://www.mja.com.au/public/issues/apr5/hillman/hillman.html (Accessed: 10th October 2007).

Hischier, R. and Walser, T. (2012) Life cycle assessment of engineered nanomaterials: State of the art and strategies to overcome existing gaps, *Science of the Total Environment*, vol. 425, 15th May, pp.271-82.

Historical Hospital Admission Records Project (2009-10) *The Electrical Department, Historical Hospital Admission Records Project* [Online]. Available at: http://www.hharp.org/library/gosh/general/electrical.html (Accessed: 10th July 2012).

Historic Hospital Admission Records Project (HHARP) (2010) *HHARP: the Historic Hospital Admission Records Project*, Kingston University [Online]. Available at: http://www.hharp.org (Accessed: 23rd August 2011).

Historic Hospital Admission Records Project (HHARP) (2010a) *HHARP: the Historic Hospital Admission Records Project*, Kingston University [Online]. Available at: http://www.hharp.org/library/gosh/general/electrical.html (Accessed: 23rd August 2011).

Historic Hospital Admission Records Project (HHARP) (2010b) *Arsenic to Zinc: the Hospital Pharmacy GOSH,* Historic Hospital Admission Records Project, Kingston University [Online]. Available at: http://www.hharp.org/library/gosh/general/pharmacy.html (Accessed: 23rd August 2011).

Hogg, C. (1999) *Patients, Power & Politics: From Patients to Citizens,* SAGE Publications.

Horton, M. and Khan, A. (2006) Medical nanotechnology in the UK: a perspective from the London Centre for Nanotechnology, *Nanomedicine: Nanotechnology, Biology, and Medicine*, vol.2, issue 1, March, pp.42-8.

Hospital Management.net (2011) University College London Hospital (UCLH), United Kingdom, *Hospital Management.net.* [Online]. Available at: http://www.hospitalmanagement.net/projects/uclh (Accessed: 14th May 2011).

House of Commons Science and Technology Committee (2004) *Too little too late? Government Investment in Nanotechnology Fifth Report of Session 2003–04, Voume 1,* The Stationery Office [Online]. Available at: http://www.publications.parliament.uk/pa/cm200304/cmselect/cmsctech/56/5602.htm (Accessed: 16th June 2008).

Howard, T. (1972) Northwick Park Hospital Harrow, Middx. Building Illustrated, *Architects' Journal*, 2nd February, pp.247-62.

Hoyt, V. and Mason, E. (2007) Nanotechnology Emerging health issues, *Journal of Chemical Health and Safety,* vol.15, issue 2, March-April, pp.10-5.

Hughes, J. (2000) The Indeterminate Building in Hughes, J. & Sadler, S. (eds.) *Non-plan, Essays on Freedom, Participation, and Change in Modern Architecture and Urbanism,* Oxford: Architectural Press, pp.90-103.

Hughes, J. (2000) The ‘Matchbox on a Muffin’: The Design of Hospitals in the Early NHS, *Medical History*, vol. 44, issue 1, January, pp.21-56.

Hughes, J. (2000a) The ‘Matchbox on a Muffin’: The Design of Hospitals in the Early NHS, *Medical History*, vol. 44, issue 1, January, pp.21-56 photograph cited from Birch-Lindgren, G. (1951) *Modern hospital planning in Sweden and other countries*, London, Constable.

Hughes, J. (2000b) The ‘Matchbox on a Muffin’: The Design of Hospitals in the Early NHS, *Medical History*, vol. 44, issue 1, January, pp.21-56 photograph cited from Archiectural Review, March 1949.

Humayun, M., Dorn, J., da Cruz, L., Dagnelie, G., Sahel, J., Stanga, P., Cideciyan, A., Duncan, J., Eliott, D., Filley, E., Ho, A., Santos, A., Safran, A., Arditi, A., Del Priore, V., Greenberg, R. and Argus II Study Group (2012) Interim Results from the International Trial of Second Sight's Visual Prosthesis, *Ophthalmology*, vol. 119, issue 4, April, pp.779-88.

Imperial College (2006) *Healthcare technology training centre to be set up at Imperial*, Imperial College London, released Monday 10th April [Online]. Available at: http://www.imperial.ac.uk/college.asp?P=7684 (Accessed: 2nd October 2012).

Interbuild (1965) Project for hospital in Venice; Architect: Le Corbusier, *Interbuild*, July, pp.10-1.

James, P. and Noakes, T. (1994) *Hospital Architecture*, Harlow: Longman.

Jerrard, J. (2006) Drug-dispensing robots drastically decrease medication errors, *The Hospitalist*, November [Online]. Available at: http://www.the-hospitalist.org/details/article/232243/Robot_Pharmd.html (Accessed: 30th August 2012).

Johnson, R. (2011) And the future is bionic, *Sunday Times Magazine*, 10th July, pp.20-2.

Jury, L. (2010) BMW that changes its shape, *Evening Standard*, Tuesday 16th February, p.24.

Kaku, M. (1998) *Visions How Science Will Revolutionize the Twenty-First Century*, Oxford University Press.

Kanellos, M. (2005) Moore says nanoelectronics face tough challenges, *CNET*, 9th March [Online]. Available at: http://news.cnet.com/Moore-says-nanoelectronics-face-tough-challenges/2100-1006_3-5607422.html?tag=cd.top (Accessed: 27th July 2011).

Kelly, V. (1934) Hospital Planning of the Future, *The Irish Builder & Engineer 75th anniversary 1859-1934*, 23rd July, pp.33-7.

Kessler, A. (2006) *The end of medicine: How Silicon Valley (and mice) will reboot your doctor*, HarperCollins Publishers.

Knight, N. (1986) The New Light: X-rays and Medical Futurism, pp.10-34 in Corn, J. (ed.) (1986) *Imagining Tomorrow: History, Technology and the American Future*, MIT Press.

Kostoff, R., Koytchef, R. and Lau, C. (2007) Global nanotechnology research literature overview, *Technological Forecasting and Social Change*, vol. 74, issue 9, pp.1733-47.

Krause, J., Winfield, A. and Deneubourg, J. (2011) Interactive robots in experimental biology, *Trends in Ecology & Evolution*, vol. 26, issue 7, July, pp.369-75.

Krawczyk, E. and Ratcliffe, J. (2005) *Imagine ahead – plan backwards: Prospective methodology in urban and regional planning*, The Futures Academy.

Kronick, D. (1962) *A History of Scientific and Technical Periodicals*, The Scarecrow Press, Inc.

Kumar, A. and Arrowsmith, J. (2006) Point-of-care testing, *Surgery (Oxford)*, vol.24, issue 10, October, p.341.

Kurzweil, R. (1999) *The age of spiritual machines when computers exceed human intelligence*, Penguin Group.

Kurzweil, R. (2006) Reinventing Humanity: The Future of Machine-Human Intelligence, *The Futurist*, March-April 2006, pp.39-46 [Online]. Available at:

http://www.kurzweilai.net/reinventing-humanity-the-future-of-human-machine-intelligence (Accessed: 12th April 2008).

Laffont, I., Biard, N., Chalubert, G., Delahoche, L., Marhic, B., Boyer, F. and Leroux, C. (2009) Evaluation of a Graphic Interface to Control A Robotic Grasping Arm: A Multicenter Study, *Archives of Physical Medicine and Rehabilitation*, vol. 90, issue 10, October, pp.1740-8.

Lampugnani, V. (eds.) (1989) *The Thames and Hudson Encyclopaedia of 20th-Century Architecture*, Thames and Hudson.

Latimer, H., Gutknecht, H. and Hardesty, K. (2008) Analysis of hospital Facility Growth: Are We Super-Sizing Healthcare? *Health Environments Research & Design Journal*, vol. 1, issue 4, pp.70-88.

Laurance, J. (2008) Martin Birchall: using stem cells to help make transplant history, *The Lancet*, vol. 372, issue 9656, 20th December, p.2104.

Leach, J. (2007) Fair of foul?, *Hospital Development*, March, pp.22-5.

Leary, J. (2010) Nanotechnology: what is it and why is small so big?, *Canadian Journal of Ophthalmology*, vol. 45, issue 5, October, pp.449-56.

Lee, J. (2004) *Guidelines on point-of-care-testing*, The Royal College of Pathologists [Online]. Available at: http://www.rcpath.org/publications-media/publications/publications (Accessed: 23rd November 2011).

Lensch, H. (2006) How to Increase Flexibility in Hospital design: Recommendations for National and International Projects, pp.500-3 in Wagenaar, C. (ed.) *The Architecture of Hospitals*, NIA Publishers.

Levere, T. (ed.) (1982) *Editing texts in the history of science and medicine*, Garland Publishing, Inc.

Levine, M., Adida, B., Mandl, K., Kohane, I. and Halamka, J. (2007) What Are the Benefits and Risks of Fitting Patients with Radiofrequency Identification Devices?, *Public Library of Science (PLOS) Medicine*, vol. 4, issue 11, November, e322, pp.1107-1. DOI: 10.1371/journal.pmed.0040322 (Accessed: 10th September 2012).

Liddell, A., Adshead, S. and Burgess, E. (2008) *Technology in the NHS Transforming the patient's experience of care*, The Kings Fund.

Lyotard, J. (1984) *The postmodern condition: A report on knowledge*. Minneapolis: University of Minnesota Press.

Macgregor, R. and Poon, G. (2003) The DNA double helix fifty years on, *Computational Biology and Chemistry*, vol. 27, issues 4-5, October, pp.461-7.

McDonagh, R. (2012) Hi-tech material a 'significant' find for Trinity boffins, *MetroHerald*, Thursday 22nd March, p.12.

McEvoy, B. (2005) *County Hospitals, Irish Free State, 1930s*, Masters of Urban and Building Conservation, School of Architecture, University College Dublin.

McGuiness, R. (2008) Robo-doctor will see you now, sir, *Metro*, Monday 11th February, p.16.

McKee, M. and Healy, J. (2002) *Hospitals in a Changing Future*, European Observatory on health Care Systems Series, Open University Press.

Maaw (2010) *Toffler's Waves – Dialectic* [Online]. Available at: http://ple.elg.ca/course/ (Accessed: 29th October 2012).

Marshall, C. and Stansby, G. (2008) Amputation, *Surgery (Oxford)*, vol. 26, issue 1, January, pp.21-4.

Masiero, S., Celia, A., Rosati, G., Armani, M. (2007) Robotic-Assisted Rehabilitation of the Upper Limb After Acute Stroke, *Archives of Physical Medicine and Rehabilitation*, vol. 88, issue 2, February, pp.142-9.

Maxwell, G. (1996) Where's the big idea? *Hospital Development*, vol. 27, issue 6, 1996 June, p.11.

Mayor, S. (2005) NHS is failing to reap benefit of new technologies, MPs say, *British Medical Journal*, vol. 330, issue 7496, 16th April, p.861.

Memorial Hall Museum Online (2012) *Pocumtuck Valley Memorial Association, Deerfield, MA. Memorial Hall Museum Online American Centuries* [Online]. Available at: http://www.americancenturies.mass.edu/collection/itempage.jsp?itemid=15077 (Accessed: 1st May 2012).

Mettaa, G., Natale, L., Nori, F., Sandini, G., Vernona, D., Fadiga, L., von Hofsten, C., Rosander, K., Lopes, M., Santos-Victor, J., Bernardino, A. and Montesanoe, L. (2010) The iCub humanoid robot: An open-systems platform for research in cognitive development, *Neutral Networks*, vol.23, issue 8-9, October-November, pp.1125-1134.

Meyer, J. (1990) A Practical Mechanical Respirator, 1929: The 'Iron Lung', *The Annals of Thoracic Surgery*, vol. 50, issue 3, September, pp.490-3.

Miller, R and Swensson, E. (2002) *New directions in hospital and healthcare facility design*, 2nd edition, New York: McGraw-Hill.

Millman, J. (2009) Email to Jonathn Millman, Head of KM and Research, NHS, 27th January 2009.

Mintzberg, H. (1987) 'The Strategy Concept 1: Five Ps for Strategy', *California Management Review, vol.* 30, issue 1, pp.11-24.

Monell, S. (1902) *Electric Solenoid bath,* A System of Instruction in X- Ray Methods and Medical Uses of Light, Hot-Air, Vibration and High-Frequency Currents [Online]. Available at: http://collectmedicalantiques.com/gallery/alternating-current (Accessed: 20th August 2013).

Monk, T. (2004) *Hospital Builders*, Chicester: Wiley-Academy.

Moore, G. (1965) Cramming more components onto integrated circuits, *Electronics Magazine*, vol. 38, issue 8, 19th April, pp.1-5.

Moore, G. (1975) Progress in Digital Integrated Electronics, *IEEE, IEDM Tech Digest*, (1975) pp.11-3.

Moore, G. (1995) Lithography and the Future of Moore’s Law, *Proceedings of SPIE*, vol. 2437, May, pp.2-17.

Morgan-Hughes, G., Roobottom, C., Manghat, N and Marshall, A. (2005) Recent advances in non-invasive cardiology: Coronary angiography using computed tomography has been underplayed, *British Medical Journal*, vol. 330, issue 7493, 26th March, pp.731-2.

Morner, K. (1903) Presentation Speech, The Nobel Prize in Physiology or Medicine 1903 in *Nobel lectures, Physiology or Medicine 1901-1921*, Elsevier Publishing Company, Amsterdam, 1967.

Morose, G. (2010) The 5 principles of ‘Design for Safer Nanotechnology’, *Journal of Cleaner Production*, vol.18, issue 3, February, pp.285-9.

Mosher, D. (2008) Robot Dials 9-1-1, *Live Science*, 15th April [Online]. Available at: http://www.livescience.com/2441-robot-dials-9-1-1.html (Accessed: 11th May 2009).

Moss, R. (1978) Systems, standards and research - a threefold attack on hospital planning problems, *Hospital Development*, July-August, pp.10-2.

Mueller, N., van der Bruggenb, B., Keuterc, V., Luisb, P., Melind, T., Pronke, W., Reisewitzf, R., Rickerbyg, D., Riosh, G. Wennekesi, W. and Nowacka, B. (2012) Nanofiltration and nanostructured membranes - Should they be considered nanotechnology or not? *Journal of Hazardous Materials*, vol. 211-2, 15th April, pp.275-80.

Museum of Historical Medical Artifacts (2012a) *Microscope 1880. Museum of Historical Medical Artifacts* [Online]. Available at:
http://www.mohma.org/instruments/category/microscope/microscope/ (Accessed: 12th April 2012).

Museum of Historical Medical Artifacts (2012b) *Whittemores vaccinator 1886. Museum of Historical Medical Artifacts* [Online]. Available at: http://www.mohma.org/instruments/category/vaccination/vaccinator_whittemores/ (Accessed: 12th April 2012).

Museum of Historical Medical Artifacts (2012c) *Piorry stethoscope 1835. Museum of Historical Medical Artifacts* [Online]. Available at: http://www.mohma.org/instruments/category/stethoscope/stethoscope__piorri/ (Accessed: 12th April 2012).

Museum of Historical Medical Artifacts (2012d) *Chloroformisateur 1890. Museum of Historical Medical Artifacts* [Online]. Available at: http://www.mohma.org/instruments/category/anesthesia/chloroformisateur/ (Accessed: 12th April 2012).

Museum of Historical Medical Artifacts (2012e) *Surgical Chest 1830. Museum of Historical Medical Artifacts* [Online]. Available at: http://www.mohma.org/instruments/category/surgery/surgical_chest/ (Accessed: 12th April 2012).

My Agriculture Information Bank (2013) *Biochemistry - Definition and History*, Available at: http://www.agriinfo.in/default.aspx?page=topic&superid=4&topicid=1567 (Accessed: 15th August 2013).

National Archives (1949) *In 1949 child patients at Braintree Hospital in Essex are lined up for school lessons*, The National Archives [Online]. Available at: http://www.nationalarchives.gov.uk/cabinetpapers/alevelstudies/origins-nhs.htm (Accessed: 19th August 2013).

National Health Service (2012) Da Vinci Robots, *NHS Choices* [Online]. Available at: http://www.nhs.uk/Search/Pages/Results.aspx?___JSSniffer=true&q=da+vinci (Accessed 31st August 2012).

National Health Service (2013) *New Hospital Project, Schedule 8 Part 3, Trust's Construction Requirements - Pharmacy*, North Tees and Hartlepool NHS Foundation Trust, p.1, 1.1.4.

National Health Service Trust (2005) *Department of Health Standard Form Project Agreement Version 3,* Department of Health [Online]. Available at: http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_4072712.zip (Accessed: 31st July 2013).

National Institute of Health Research's (NIHR) (2011) *NHS Physical Environment Research Programme-list of projects*, NHS [Online]. Available at:

http://www.nihr.ac.uk/files/pdfs/NHS%20Physical%20Environment%20Research%20Programme%20-%20list%20of%20projects%20(updated%20May%202011).pdf (Accessed: 25th June 2011).

Nelson, B. and Rajamani, R. (2005) Biomedical micro-robotic system, *MICCAI 2005 8th International Conference on Medical Image Computing and Computer Assisted Intervention*. Palm Springs, CA: 26th - 29th October [Online]. Available at: http://www.miccai2005.org (Accessed: 14th September 2012).

Nerdinger, W. (ed.) (1999) *Alvar Aalto, Toward a Human Modernism*, Prestel Verlag.

Neville, M. (2008) Rebuilding the Mat in the Contemporary Urban Landscape, *On Site Review*, vol.19 Spring/Summer, pp.1-3.

New London Architecture (2005) *Capital Health London's New Health Care Estate,* Department of Health.

NHS Barts Health NHS Trust (2011) Vital statistics 2009/10, *NHS* [Online]. Available at: http://www.bartsandthelondon.nhs.uk/about-us/annual-report-and-accounts/annual-review-2009-10/vital-statistics-2009-10/ (Accessed: 27th March 2011).

NHS Chelsea and Westminster (C&W) NHS Foundation Trust (2009) *Our History*, NHS [Online]. Available at: http://www.chelwest.nhs.uk/about-us/history.htm (Accessed: 11th March 2009).

NHS Chelsea and Westminster (C&W) NHS Foundation Trust (2009a) A&E (including Urgent Care Centre), NHS [Online]. Available at: https://www.chelwest.nhs.uk/services/emergency_dept.htm (Accessed: 11th March 2009).

NHS Guy's and St. Thomas' NHS Foundation Trust (2011) *How are we doing? Reporting back on 2010/11*, NHS [Online]. Available at: https://www.guysandstthomas.nhs.uk/about/organisation/vitalstatistcis.aspx (Accessed: 27th March 2011).

NHS Trust Archivists (2008) *NHS 60th Anniversary exhibition*, 5th July 2008, panels 7-12. In collaboration with NHS Trust archivists an exhibition display created to celebrate the NHS's 60th anniversary [Online]. Available at: http://www.bartsandthelondon.nhs.uk/assets/docs/About-us/Museums/Panels7-12version.pdf (Accessed: 13th April 2008).

NHS University College London Hospitals NHS Foundation Trust (2011) Emergency Department , *NHS* [Online]. Available at: http://www.uclh.nhs.uk/ourservices/serviceA-Z/ES/AE/Pages/Home.aspx (Accessed: 27th March 2011).

Nield, L. (2008) Postscript: Re-inventing the hospital, pp.251-268 in Prasad, S. (ed.) (2008) *Changing Hospital Architecture*, RIBA Publishing.

Nield, L. (2003) Hospitals are not designed for the 21st century*, Architects for health,* Lecture given during Architecture Week 2003. Available at: http://www.architectsforhealth.com/library/event-26june2003-d.html (Accessed: 9th September 2008).

Nightingale, N. (1969) *Notes on Nursing What it is, and what it is not*, Dover Publications.

Noakes, A. (1982) Planning & Design DHSS Development Projects: An architectural history, *Planning & Design*, pp.118-31.

Noble, D. (1962) Hospital design today. 8, X-ray departments, *Builder*, 14th September, pp.527-8.

Norman, D. (2007) The Design of Future Things, BasicBooks.

Nottingham Spirk (2012) *Blood Analyzer: Sophisticated Workstation Capable of Performing All Elements of Blood Analysis*, Nottingham Spirk [Online]. Available at: http://www.nottinghamspirk.com/index.php/business-development/medical-device-design/blood-analyzer/ (Accessed: 11th December 2012).

Novak, J. & Godwin, D. (1984) *Learning How to Learn*, Cambridge University Press.

Noviant, L. (1933) Tuberculosis sanatoria: at Paimio, Finland; Architect: A. Aalto; at Montana, Switzerland; Architect: R. Wander; various examples in United States of America, *Architectural Review,* September, pp.85-90.

Nuffield Provincial Hospitals Trust (1955) *Studies in the function and design of hospitals*, London, OUP.

Nutton, V. (2006) The Rise of Medicine, pp. 46-70 in Porter, R. (2006) *The Cambridge History of Medicine*, Cambridge University Press.

Or, J. (2010) A hybrid CPG-ZMP control system for stable walking of a simulated flexible spine humanoid robot, *Neural Networks*, vol. 23, issue 3, April, pp.452-60.

Orrell, D. (2007) *The Future of everything: The science of prediction*, Basic Books.

Palagi, S., Pensabene, V., Mazzolai, B. and Beccai, L. (2011) Novel Smart Concepts for Designing Swimming Soft Microrobots, *Procedia Computer Science*, vol. 7, pp.264-5.

Pearce, D. (1978) Hospitals for humans: the 'nucleus' principle for building and expanding hospitals, *Building Design*, no. 400, 16th Jun, p.18-9.

Pearson, P. (1978) *Alvar Aalto and the International Style*, Whitney Library of Design, Watson-Guptill Publications.

Peterson, R. (2004) Microtechnology, Energy Applications of, *Encyclopedia of Energy*, Elsevier Inc., volume 4.

Peterson, R. B. (2004) Microtechnology, Energy Applications of, *Encyclopedia of Energy*, pp.17-30.

Pfeiffer, E. (1998) Ray Kurzweil: The Ultimate Thinking Machine, *Forbes ASAP*, 6th April [Online]. Available at: http://www.forbes.com/asap/1998/0406/017.html (Accessed: 21st February 2012).

Phisick Medical Antiques (2013) *Early 19th C German Neurosurgical Set*, Phisick Medical Antiques [Online]. Available at: http://phisick.com/item/early-19th-c-german-neurosurgical-set/ (Accessed: 16th August 2103).

Pica, A. (1965) Project for hospital in Venice; Architect: Le Corbusier, *Domus*, June, p. 4-7.

Pickstone, J. (2006) Medicine, Society, and the State, p.260-297 in Porter, R. (2006) *The Cambridge History of Medicine*, Cambridge University Press.

Ponnusamy, K., Mohr, C. & Curet, M. (2011) In Brief, *Current Problems in Surgery*, vol.48, issue 9, September, pp.570-5.

Porter, R. (2006) *The Cambridge History of Medicine*, Cambridge University Press.

Porter, R. (1996) *The Cambridge Illustrated History of Medicine*, Cambridge University Press.

Porter-O’Grady, T. (2007), Innovation, Architecture, and Quantum Reality: Synthesis in a new age for healthcare. *Health Environments Research & Design Journal*, vol. 1, issue 1, Fall, pp.17-9.

Powell, P. (1966) Architects’ approach to architecture: Philip Powell, *RIBA Journal*, March, pp.116-27.

Present and future of European hospitals heritage (PAPHE) (2001) London: Royal London Hospital, *Present and future of European hospitals heritage*, September 2001 [Online]. Available at: http://europaphe.aphp.org/en/f_uni_lon_roy.html (Accessed: 7th May 2011).

Present and future of European hospitals heritage (PAPHE) (2001a) London: St Thomas's Hospital, *Present and future of European hospitals heritage*, September 2001 [Online]. Available at: http://europaphe.aphp.org/en/f_uni_lon_stho.html (Accessed: 7th May 2011).

Present and future of European hospitals heritage (PAPHE) (2001b) London: University College Hospital, *Present and future of European hospitals heritage*, September 2001 [Online]. Available at: http://europaphe.aphp.org/en/f_uni_lon_uni.html (Accessed: 7th May 2011).

PRIME Faraday Partnership (2002) *An Introduction to MEMS (Micro-electromechanical Systems)*, PRIME Faraday Partnership, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough. Available at: http://www.lboro.ac.uk/microsites/mechman/research/ipm-ktn/pdf/Technology_review/an-introduction-to-mems.pdf (Accessed: 14th May 2009).

Quan, W., Niwa, H., Ishikawa, N., Kobayashi, Y. and Kuno, Y. (2011) Assisted-care robot based on sociological interaction analysis, *Computers in Human Behavior*, vol. 27, issue 5, September, pp.1527-34.

Quantrill, M. (1983) *Alvar Aalto: A critical study*, Martin Secker & Warburg Limited.

Radnedge, A. (2010) World-first heart op by a robot arm, *Metro*, Thursday 29th April, p.23.

Randhawa, K. (2011) London hospitals face care crisis as PFI debts force cuts to services, *Evening Standard*, Thursday 22nd September, p.10.

Ratcliffe, J. and Sirr, L. (2003) *The Prospective Process Through Scenario Thinking for the Built and Human Environment: a tool for exploring urban futures*, The Futures Academy, Dublin Institute of Technology.

Ratcliffe, J. (2004) Scenario Planning: strategic interviews and conversations, *Foresight*, vol. 4, issue 1, pp.19-30.

Ratcliffe, J. (2000) *Scenario Building: A Suitable Method for Strategic Construction Industry Planning?*, The Futures Academy, Dublin Institute of Technology.

Rattner, D. (1999) Future directions in innovative minimally invasive surgery, *The Lancet*, vol. 353, Supplement 1, April, pp.S12-5.

Reed, P. (ed.) (1998) *Alvar Aalto Between Humanism and Materialism*, The Museum of Modern Art, Thames and Hudson.

Richardson. H. (1998) *English Hospitals 1660-1948 A survey of their architecture and design*, Royal Commission on the Historical Monuments of England.

Richardson. R (2008) *The Making of Mr. Gray's Anatomy Bodies, books, fortune, fame,* Oxford University Press.

Ringland, G. (1998) *Scenario Planning*, Wiley, Chichester.

Rios, A. Zougaghb, M., and Avilaa, M. (2012) Miniaturization through lab-on-a-chip: Utopia or reality for routine laboratories? A review, *Analytica Chimica Acta*, vol.740, 31st August, pp.1-11.

Rivett, G. (1986) *The Development of the London Hospital System 1823-1982*, London: King’s Fund [Online]. Available at: http://www.nhshistory.com/Londonshospitals.htm (Accessed: 3rd March 2010).

Roentgen, W. (1896) On a New Kind of Rays. Translated by Arthur Stanton. *Nature*, vol. 53, 23rd January, pp.274-6.

Rogers, D. (2009) Unison calls for PFI to be scrapped, *Building Design*, no.1873, 19th June, p.5.

Rosen, R. (2002) Introducing new technologies, pp.240-51 in McKee, M. & Healy, J. (2002) *Hospitals in a changing Europe*, *European Observatory on Health Care Systems Series*, Open University Press.

Rosenfield, I. and Rosenfield, Z. (1969) *Hospital Architecture and Beyond*, Van Nostrand Reinhold Company.

Rossini, P., Micera, S., Benvenuto, A., Carpaneto, J., Cavallo, G., Citi, L., Cipriani, C., Denaro, L., Denaro, V., Di Pino, G., Ferreri, F., Guglielmelli, E., Hoffmann, K., Raspopovic, S., Rigosa, J., Rossini, L., Tombini, M. and Dario, P. (2010) Double nerve intraneural interface implant on a human amputee for robotic hand control, *Clinical Neurophysiology*, vol. 121, issue 5, May, pp.777-83.

Rostenburg, B. (2006) *The Architecture of Medical Imaging: Designing Healthcare Facilities for Advanced Radiological Diagnostic and Therapeutic Techniques*. 2nd Edition. Wiley.

Rostenberg, B. and Barach, P. (2012) Design of cardiovascular operating rooms for tomorrow's technology and clinical practice - Part 2, *Progress in Pediatric Cardiology*, vol. 33, issue 1, January, pp.57-65.

Rubin, H., Owens, A. and Golden, G. (1998) *An Investigation to Determine Whether the Built Environment Affects Patients' Medical Outcomes. Status report*, The Center for Health Design, Baltimore.

Ryan, S. (2013) Future of Southlands Hospital block is unclear, *The Argus* [Online]. Available at: http://www.theargus.co.uk/news/10392800.Future_of_Southlands_Hospital_block_is_unclear/ (Accessed: 19th August 2013).

Sadee, W. (2011) Genomics and personalized medicine, *International Journal of Pharmaceutics*, vol. 415, issues 1-2, August, pp.2-4.

Sahoo, S., Parveen, S. and Panda, J. (2007) The present and future of nanotechnology in human health care, *Nanomedicine: Nanotechnology, Biology, and Medicine*, vol. 3, issue 1, March, pp.20-31.

Sanders, R. (2005) Medical Technology: A critical perspective - learning to become loving resistance fighters, *Internet Journal of Medical Technology*, vol.2 no.1, pp.1-16 [Online]. Available at http://www.ispub.com/journal/the-internet-journal-of-medical-technology/volume-2-number-1/medical-technology-a-critical-perspective.html (Accessed: 5th August 2008).

Sarkis, H. (ed.) (2001) *Case: Le Corbusier's Venice Hospital and the Mat Building Revival*, Prestel.

Sarkis, H. (2001) The Paradoxical Promise of Flexibility, pp.81-9 in Sarkis, H. (ed.) (2001) *Case: Le Corbusier's Venice Hospital and the Mat Building Revival*, Prestel.

Satava, R. (1998) Transitioning to the future, *Journal of American College of Surgeons*, vol. 186, issue 6, June, pp. 691-2.

Scher, P. (2006) Fit for purpose, *Hospital Development*, June, p.38.

Scherberge, H. (2009) Neural control of motor prostheses, *Current Opinion in Neurobiology*, vol.19, issue 6, December, pp.629-33.

Schildt, G. (1986) *Alvar Aalto Part II The Decisive Years*, Rizzoli.

Schildt, G. (1994) *Alvar Aalto: The Complete Catalogue Of Architecture, Design and Art*, Academy Editions.

Schmitz, G., Aslanidis, C. and Lackner, J. (2001) Pharmacogenomics: implications for laboratory medicine, *Clinica Chimica Acta*, vol. 308, issues 1-2, June, pp.43-53.

Schumpeter, J. (1961) *The theory of economic development*, Oxford University Press, London.

Schwartz, A. (2011) The Robotic Nurse That Can Pick You Up, *Fast Company*, 2nd August. Available at: http://www.fastcompany.com/1771029/robotic-nurse-can-pick-you (Accessed 1st September 2012).

Schwartz & Ogilvy (quote from) 1998 in Ratcliffe, J. and Sirr, L. (2003) *The Prospective Process Through Scenario Thinking for the Built and Human Environment: a tool for exploring urban futures*, The Futures Academy.

Science Museum (2013) *Electrotherapeutic d'Arsonval cage by Richard Heller, Paris*, Science Museum [Online]. Available at: http://www.sciencemuseum.org.uk/broughttolife/objects/display.aspx?id=92779 (Accessed: 19th January 2013).

Shoemaker, P. (1998) Twenty Common Pitfalls in Scenario Planning in Fahey, L. and R. Randal (eds) (1998) *Learning from the Future*, John Wiley, Toronto.

Wack, P. 1985, "The Gentle Art of Reperceiving",

Smith, J. (1984) Hospital Building in the NHS. Ideas and designs II: harness and nucleus, *British Medical Journal*, vol. 289, 1st December, p.1513-6.

Smith, M. (2012) Bioelectrodes, *The Health Science* [Online]. Available at: http://thehealthscience.com/content.php?128-Bioelectrodes/view/21 (Accessed: 20th August 2013).

Smithson, A. (2001) How to Recognize and Read Mat Building, pp.x-y in Sarkis, H. Eds. (2001) *Case: Le Corbusier's Venice Hospital and the mat building revival*, New York: Prestel.

Smyth, P., Francis, S. and Whitehouse, N. (2006) *How do we lengthen the useful life of hospital buildings A study on the design of hospitals to improve their adaptability to change*, Esha Architects and NHS Estates.

Spring, M. (1979) Sixties panacea: why designers of teaching hospitals still cling to the outmoded concepts of large-scale buildings, high technology and flexibility, *Building*, vol. 236, issue 7081 (13), 30th March, pp.54-5.

Srinivasan, R. (2008) Sources, characteristics and effects of emerging technologies: Research opportunities in innovation, *Industrial Marketing Management*, vol. 37, issue 6, August, pp.633-640.

St. Bartholomew's Hospital Archives & Museum (2009) *St Bartholomew's Hospital*, St. Bartholomew's Hospital Archives & Museum.

Steiner, D. and Phillips, C. (1993) *Historical Journals A Handbook for writers and Reviewers*, 2nd Edition, McFarland & Company, Inc. Publishers.

Stylios, G., Giannoudis, P. and Wan, T. (2005) Applications of nanotechnologies in medical practice, *Injury*, vol. 36, issue 4, November, pp.S6-13.

Sullivan, L. (1896) The tall office building artistically considered, *Lippincott's Magazine*, vol. 57, March, pp.408-9.

Taavitsainen, I. and Pahta, P. (2004) *Medical and Scientific writing in Late Medieval English*, Cambridge University Press.

Taniguchi, N. (1974) 'On the Basic Concept of 'Nano-Technology'. *Proceedings of the International Conference on Production Engineering, Tokyo, 1974, Part II*. Japan Society of Precision Engineering.

Taylor, J. (1991) *Hospital and Asylum Architecture in England 1840-1914, Building for Healthcare*, London: Mansell.

The Charity Commission for England and Wales (2011) *Trusts and Trusteeship under NHS Acts, 1946-2006*, The Charity Commission for England and Wales [Online]. Available at: http://charitycommission.gov.uk/detailed-guidance/specialist-guidance/nhs-charities-guidance/trusts-and-trusteeship-under-nhs-acts,-1946-2006/ (Accessed: 7th August 2013).

The Lancet (1939) Hospitals in Emergency: The Scheme for London, *The Lancet*, vol.233, issue 6030, 25th March, pp.723-5.

The Lancet, editorial (2003) Nanomedicine: grounds for optimism, and a call for papers, *The Lancet*, vol. 362, issue 9385, 30th August, p.673.

The Lancet (2007) The risks of nanotechnology for human health, *The Lancet*, vol. 369, issue 9568, 7-13th April, p.1142.

thenextwavefutures (2009) The end of Moore's Law, *thenextwavefutues* [Online]. Available at: http://thenextwavefutures.wordpress.com/2009/08/02/the-end-of-moores-law/ (Accessed: 13th November 2011).

The Royal Society & The Royal Academy of Engineering (2004) *Nanoscience and nanotechnologies: opportunities and uncertainties*, The Royal Society [Online]. Available at: http://royalsociety.org/policy/publications/2004/nanoscience-nanotechnologies/ (Accessed: 27th November 2010).

Thompson, D. (1983) Design trends within the UK for new hospital buildings, *World Hospitals*, vol. 19, issues 1-2, April, pp.69-72.

Thomson, J. and Goldin, G. (1975) *The Hospital: A social and architectural history*, New Haven; Yale University Press.

Toffler, A. (1970) *Future Shock*, Bantam Book, Inc.

Toffler, A. (1980) *The Third Wave*, William Collins Sons & Co. Ltd.

Tomlinson, B. (1992) *Report of the inquiry into London's Health Service, Medical Education and Research*, Presented to the Secretaries of State for Health and Education by Sir Bernard Tomlinson October 1992, The Stationery Office.

Torgerson, P. and Torgerson, D. (2009) Public health and bovine tuberculosis: what's all the fuss about?, *Trends in Microbiology*, vol. 18, issue 2, February, pp.67-72.

Truax, C. (1899) The Mechanics of surgery, Truax, Chicago, p.7 in Williams, T. (1978) *A history of technology. Vol.7, Twentieth century c.1900 to c.1950,* Oxford: Clarendon Press.

T.S.W (1934) William Hewson, *The American Journal of Surgery,* vol. 25, issue 2, August, p.361.

Ulrich, R. (1984) View through a window may influence recovery from surgery, *Science,* vol. 224, issue 4647, 27th April, pp.420-1.

Ulrich, R., Quan, X., Zimring, C., Joseph, A. and Choudhary, R., (2004) *The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-lifetime Opportunity,* The Centre for Health Design.

Ulrich, R., Zimring, C., Zhu, X., et al., Zhu, X., DuBose, J., Seo, H., Choi, Y., Quan, X. and Joseph, A. (2008) A review of the research literature on evidence-based healthcare design, *Healthcare Environments Research and Design Journal*, vol.1, issue 3, pp.61–125.

United Nations (1992) *UN Convention on Biological Diversity, Article 2 Use of Terms.*

University Hospitals Birmingham (2011) *Queen Elizabeth Birmingham Hospital Pharmacy*, University Hospitals Birmingham [Online]. Available at: http://www.uhb.nhs.uk/Images/QueenElizabethPhotos/QehHistorical11.jpg (Accessed: 1st November 2011).

University of Leicester (2011) *University of Leicester scientists deploy space-age technologies to detect illness at science-fiction style 'sick bay'*, University of Leicester Press Office, 1st September 2011 [Online]. Available at: http://www2.le.ac.uk/offices/press/press-releases/2011/august/university-of-leicester-scientists-deploy-space-age-technologies-to-detect-illness-at-science-fiction-style-sick-bay (Accessed: 10th November 2012).

University of Pennsylvania Health System (2012) Dr. Henry Fisher examines specimen, Pathology Lab, c.1890s. Pennsylvania Hospital Historic Collections [Online]. Available at: http://www.uphs.upenn.edu/paharc/collections/gallery/departments/Pathology.html (Accessed: 1st May 2012).

University of Rochester Medical Centre (1920s) *Patients at the J.N. Adam Memorial Hospital, a tuberculosis sanitarium south of Buffalo, N.Y 1920,* Edward G. Miller Library, University of Rochester Medical Center [Online]. Available at: http://www.urmc.rochester.edu/hslt/miner/historical_services/photo_exhibits/ (Accessed: 1st May 2012).

University of Sydney (2012) *Compound microscope, E. Leitz, Wetzlar, Germany, 1894, (No. 29368),* University of Sydney [Online]. Available at: http://sydney.edu.au/museums/events_exhibitions/macleay_past/microscope_design.shtml (Accessed: 15th April 2012).

van den Berg, A. (2005) *Healing Impacts of Healing Environments A review of evidence for benefits of nature, daylight, fresh air, and quiet in healthcare settings*, University of Groningen.

van Susteren, A. (2005) *Metropolitan World Atlas*, 010 Publishers, Rotterdam.

Valeroa, R., Koa, Y., Chauhana, S., Schatloffa, O., Sivaramana, A. , Coelhoa, R., Ortegaf, F., Palmera, K., Sanchez-Salasf, R. , Davila, H. , Cathelineauf, X. and Patela, V. (2011) Robotic surgery: History and teaching impact, *Actas Urológicas Españolas (English edition)*, vol. 35, issue 9, October, pp.540-5.

Wagenaar, C. (2006) *The Architecture of Hospitals*, NIA Publishers.

Walsh, G. (2003) Pharmaceutical biotechnology products approved within the European Union, *European Journal of Pharmaceutics and Biopharmaceutics*, vol.55, issue 1, January, pp.3-10.

Wanless, D., Appleby. J., Harrison, A. and Patel, D. (2007) *Our Future Health Secured? A review of NHS funding and performance*, The King's Fund.

Warwick, K. (2007) Upgrading Humans - Technical Realities and New Morals, *The Jounral of Geoethical Nanotechnology*, p.3 [Online]. Available at: http://www.terasemjournals.org/GNJournal/GN0204/kw3.html (Accessed: 7th July 2013).

Warwick, K. and Ruiz, V. (2008) On linking human and machine brains, *Neurocomputing*, vol. 71, issues 13-5, August, pp.2619-24.

Watkin, B. (1978) *The National Health Service: The First Phase 1948-1974 and After*, London: George Allen & Unwin.

Weeks, J. (1963-4) Indeterminate architecture, *Bartlett Society Transactions*, 1963-1964, vol. 2, pp.85-106.

Weeks, J. (1966) Indeterminate hospital design on urban sites, *Hospital Management, Planning & Equipment*, June, pp.338-41.

Weeks, J. (1999) Changing spaces: Northwick Park; Architects: Llewelyn-Davies Weeks, *Hospital development*, vol. 30, issue 7, July, pp.15-6.

Wellcome Library (1896) *The operating theatre, Metropolitan Hospital, London* [Photograph]. Metropolitan Hospital photograph album, London [Online]. Available at: http://wellcomeimages.org/ (Accessed: 27th March 2012).

Wesolowski, J. and Lev, (2005) CT: History, Technology, and Clinical Aspects, *Seminars in Ultrasound, CT and MRI*, vol. 26, issue 6, December, pp.376-9.

Willcocks, A. (1967) *The Creation of the National Health Service A study of pressure groups and a major social policy decision*, London: Routledge and Kegan Paul.

Williams, S. (1997) Modern medicine and the 'uncertain body': From corporeality to hyper-reality? *Social Science & Medicine*, vol. 45, issue 7, October, pp.1041-9.

Williams, T. (1978) *A history of technology, Vol.7, Twentieth century, c.1900 to c.1950*, Oxford: Clarendon Press.

Williams, T. (1978) *A history of technology, Vol.6, Twentieth century, c.1900 to c.1950*, Oxford: Clarendon Press.

Willis, J. (2002) Machines for Living, *Architecture Australia*, vol.91, issue 4, July/August, pp.46-7.

Willis, T. (2008) An Anaesthesia HistoryTimeline - The Anaesthesia Heritage Centre at 21 Portland Place, *Anaesthesia News*, issue 249, April p.27-9. Available at: http://www.aagbi.org/publications/anaesthesia-news/april-2008-0. Accessed: 23rd April 2010. Anaesthesia Heritage Centre, Association of Anaesthetists of Great Britain and Ireland.

Wilson, C. (1999) The impact of medical technologies on the future of hospitals, *British Medical Journal*, vol. 319, issue 7220, 13th November, pp.1287-9.

Winston, A. (2009) Government should scrap PFI, says Rogers, *Building Design*, no. 1858, 6th March, p.1.

World Economic Forum Global Agenda Council (2010) *Definition of Emerging Technologies*, November 2010 at the Global Agenda Council Summit, Dubai [Online]. Available at: http://www.matterforall.org/projects/emerging-technology-goverance/2/ (Accessed 5th August 2013).

Wulfing-Luer, H. (1897) *Luer's syringe*. Patent: US583382.

Yeang, K. (2008) *Ecodesign: A Manual for Ecological Design*, John Wiley & Sons.

Yih, T. and Moudgil, V. (2007) Nanotechnology comes of age to trigger the third industrial revolution, *Nanomedicine: Nanotechnology, Biology and Medicine*, vol. 3, issue 4, December, p.245.

Zielinska, T., Chew, C., Kryczka, P. and Jargilo, T. (2009) Robot gait synthesis using the scheme of human motion skills development, *Mechanism and Machine*

Theory, vol. 44, issue 3, March, pp.541-58.

GLOSSARY

Biotechnology: Biotechnology consists of four sub fields (AGRIFOR Consult, 2005[1]). Red biotechnology relates to the medical production of antibiotics and genomic manipulation. White/grey biotechnology relates to industrial production. Green biotechnology is assocaied with agricultural production and environmental safety while blue biotechnology relates to aquaculture.

Consortia: A consortium consists of multi-disciplinary companies, such as, construction and investment businesses, that form a joint venture to finance, design, deliver and maintain NHS hospitals. Once built, consortia are contracted to maintain the hospital for a period between 30-40 years while hospital space is rented to the NHS for the same period of time.

Classical Humorism - humoral care: Classical humoral medicine and humoral care are based upon the bloods and humours of bodies. Medical knowledge was based on animal autopsies and adopted by Ancient Greek and Roman physicians and philosophers.

Design Team Members (DTMs): This definition describes the collective team members included within a PFI project. Design team members include: all Trust (normally the Client) members, architects, health planners, medical planners, engineers, medical equipment specialists, contractors and many more.

---

[1] AGRIFOR Consult, 2005. *Guidelines for Green, White, Blue and Red Biotechnologies.* Contract No 2004/87266. 42p + Annexes 179p. [Online]. Available at: http://www.sbcbiotech.nl/page/downloads/Final Report - Guidelines Biotech DCs 2005 Annexes.pdf (Accessed: 19th April 2010).

Emerging Technologies (ETs): The definition of ETs from World Economic Forum Global Agenda Council (WEFGAC) Emerging Technologies meeting in Nov 2010 states:

> ETs arise from new knowledge or innovative application of existing knowledge that rapidly develop new capabilities that create entire new industries. Currently nanotechnologies, synthetic biology, genomics, converging technologies, robotics, geoengineering and others are considered to be ETs (WEFGAC, 2010).

Private Finance Initiative (PFI): Established during the 1990's by the British Government, the PFI process is a method of funding public infrastructure projects, such as hospitals and schools, with private capital investment. A first phase of new PFI hospitals was opened in 2001 followed by a second phase of PFI hospitals which were completed in 2003.

Urgent-Acute-Trauma (UAT): Hospitals contain many different types of patient flows such as, elective care and UAT care. The UAT hospital terminology describes; the type of patient admitted (urgent, acute of traumatic); the medical practice to deliver the patient's care; the flows and spaces associated with the patient's treatment within hospitals