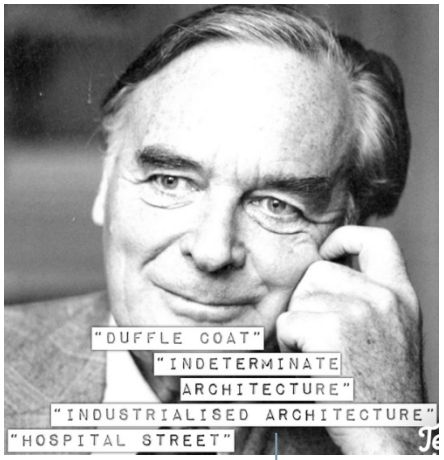
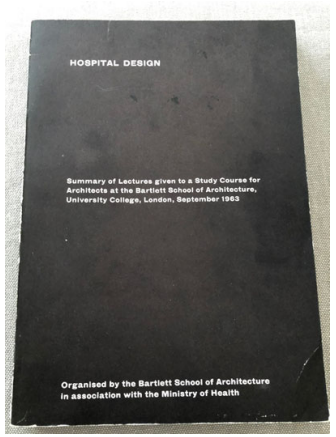
Advancing capabilities in hospital infrastructure project delivery

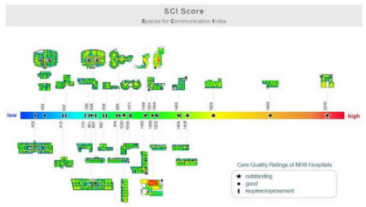
Dr Grant Mills
(UCL)

UCL Bartlett (History)

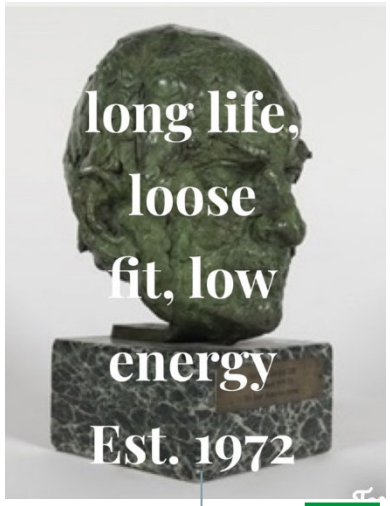


John Weeks (UCL and Llewelyn Davies) - recognised as having set the agenda for the design of the modern hospital. Specifically, the principles of 'Indeterminate Architecture', 'Industrialised and Internationalised Hospital Architecture', and 'Flexible Hospital Design'. He also coined the terms 'hospital street' and the 'duffle coat' that are still widely used today.





Intellectual rigour in the design of hospitals



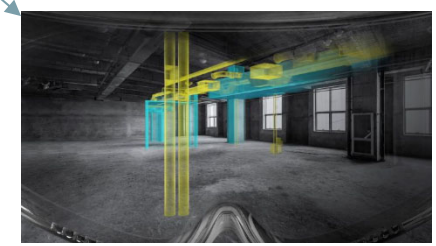
Sir Alexander John Gordon - coined the phrase 'long life, loose fit, low energy', as a maxim for good building.

Delivering a 'Net Zero' National Health Service

Bill Hillier - What do we mean by building function?

36 Academics in the Bartlett Health space and 19 PhD students

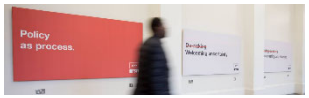
100s of connections with academics in UCL engineering, public health, social sciences, applied health research and clinical practice.



The Bartlett Centre for Advanced Spatial Analysis

The Bartlett School of Planning

The Bartlett Development Planning Unit



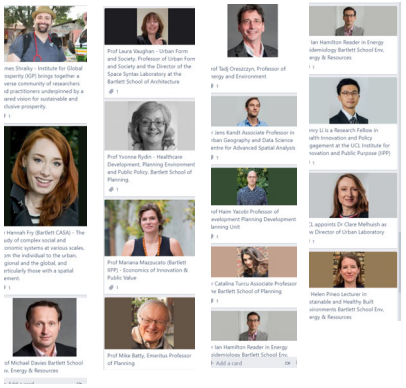
UCL Institute for Innovation and Public Purpose

UCL Institute for Sustainable Heritage

UCL Urban Laboratory

UCL Institute for Sustainable Resources

UCL Institute for Global Prosperity



Design for Manufacture MArch

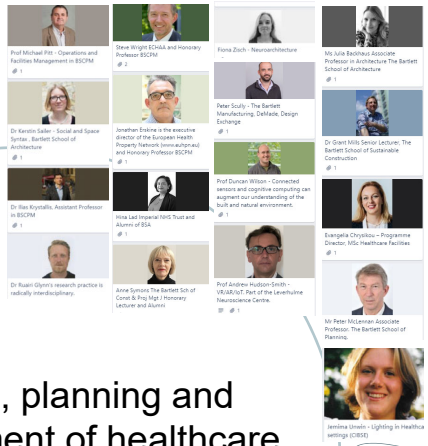
Space Syntax: Architecture and Cities MSc/MRes

Design for Performance and Interaction MArch

Connected Environments MSc

Digital Engineering Management MSc

Light and Lighting MSc



Design, planning and management of healthcare facilities and projects

Healthcare Facilities MSc (Healthcare built environments and architecture - The Bartlett's new Real Estate Institute)

The Bartlett School of Architecture

The Bartlett School of Sustainable Construction

Institute for Digital Innovation in the Built Environment

The Bartlett Real Estate institute

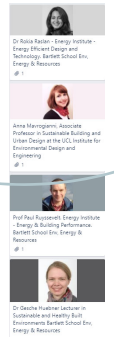
UCL Bartlett Health

Public health and the built environment

Health in Urban Development MSc (Focused on the Global South - Bartlett Development Planning Unit)

Sustainable building design and the health and wellbeing of occupants

Health, Wellbeing and Sustainable Buildings MSc (environmental design and engineering - Bartlett School of Environment, Energy & Resources)



The Bartlett School of Environment, Engineering, Energy and Resources – UCL Energy Institute

The Bartlett School of Environment, Engineering, Energy and Resources – UCL Institute for Environmental Design and Engineering

Structure

- UCL Bartlett Health
- COVID (the all pervasive context)
- ESRC Transforming Construction Research Project – Challenging Space Frontiers

UK Response

January - February	March

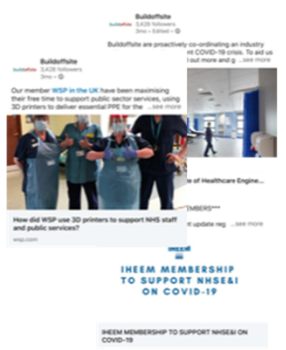
NHS Providers raise concern over investment in NHS estates

Designers, engineers and suppliers raise concerns over hospital procurement of new UK hospitals

Manufacturers rally support

Construction site welfare facilities provided to support NHS services

Government makes financial commitment to manufacturing and construction sectors



Institutions supporting communication, coordination and directing towards shared goals

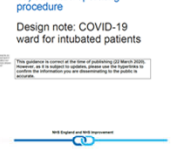
Government commitment to manufacturing celebrated

Focused service provision

Celebrating facilities management and cleaning

Expansion of ICUs and reconfiguration of operating theatres and recovery areas

Key institutions become directly involved in developing technical / engineering standards

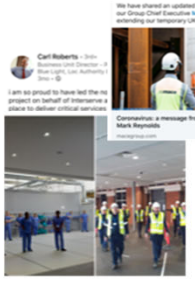


Rapid COVID19 response design note production

Direct Gov communication to the construction industry

Transforming construction celebrating collaborative efforts and need for platforms

Evidence of multi-factorial impacts of COVID start to emerge



Clear guidance on safe working during COVID / CLC guidance / shared message

Shared effort to gain international knowledge about the response effort

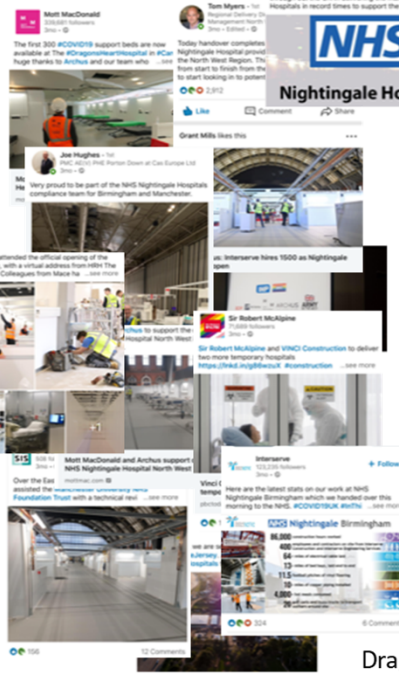
UK Response

April	May-July

Rapid procurement with direct approach to organisations best for task

Highly responsive design, innovation, manufacture and assembly to make best use of equipment and space

Private and public sector coordinated response



Key UK Institutions celebrate the efforts of key parties / organisations

Key UK Institutions contribute to International effort

Organisations reflect on how best they can deliver improved productivity Post-COVID

Impact of new and refurbishment projects puts pressure on existing infrastructure. Rapid installation to increase oxygen capacity

First Nightingale Hospital Completed in London – the collaborative efforts of all contributions are heralded

Shared pride in being part of the Nightingale effort – Birmingham, Manchester, Jersey and Cardiff completed

Dragon's Heart Hospital in Cardiff, NHS Louisa Jordan Hospital in Glasgow, and an extension to Belfast City Hospital

Strong purpose and collective pride in the speed of the response

Multi-directional shared commitments

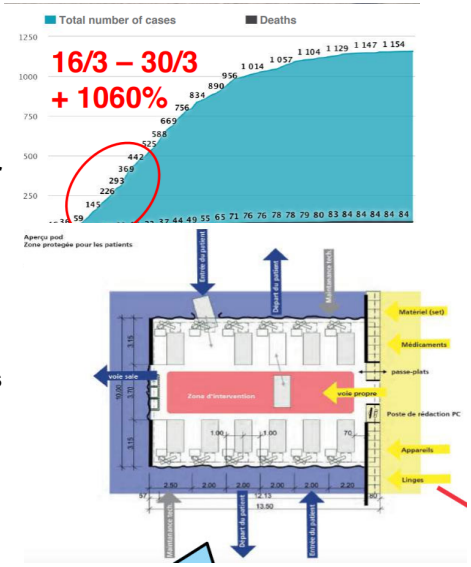
Industry wide knowledge sharing about what was done and how

Reflections on what the industry need to work more collaboratively

Variation in International Response

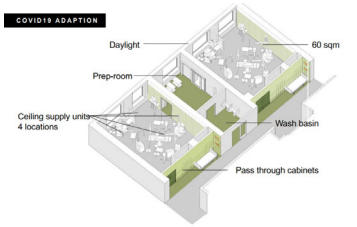
Follow the data: Fribourg, Switzerland

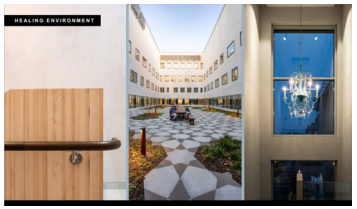
- Example of Italy close at hand.
- Plans for surge capacity … but … **never implemented**.
- Highly **integrated approach to data** gathering, analysis, decision-making.
- Strong, frontline-driven, clinically appropriate use of thresholds.
- Focus on patient and public communication.
- **Recognition that staff availability was even more important than space or equipment**.
- Centralised critical decision-making; decentralised problem solving.



Transformation mid-stream: Huddinge, Sweden

- No lock down!
- Nearing completion: a new operating block to replace old technical systems and to accommodate modern working practices.
- **OT's repurposed as ICU environments** …
- … but **keeping the design features of the original plan**.
- A design, engineering and technical team already on site.
- Close working relationship with clinicians and management.





Use everything you have: Hospital del Mar, Barcelona, Spain

- Surge planning: **from 40 to 196 ICU beds in 4 weeks**.
- **Transform the day hospital** ('from armchairs to beds')
- Occupy unused space (an empty 1st floor).
- Use non-hospital but closely linked estate (sports arena).
- Worst case scenario – use the car park?
- Lessons:
  - Design 'accordion hospitals'.
  - Dedicated but separate space for ICU patients' families.

'Forewarned is forearmed': Covid-19 in Taiwan

- **Previous experience of SARS**: hospitals and health centres equipped for ID outbreaks; staff well trained.
- **Well-resourced centre for disease control**: rapid processing of information.
- Strong links between ID expertise and government: rapid decision-making.
- Long term commitment to healthy urban environments.
- **Culture – respect for public health messages; mask wearing; familiarity with hygiene measures**.
- Universal health coverage.
- Hospital design: adaptable and flexible.

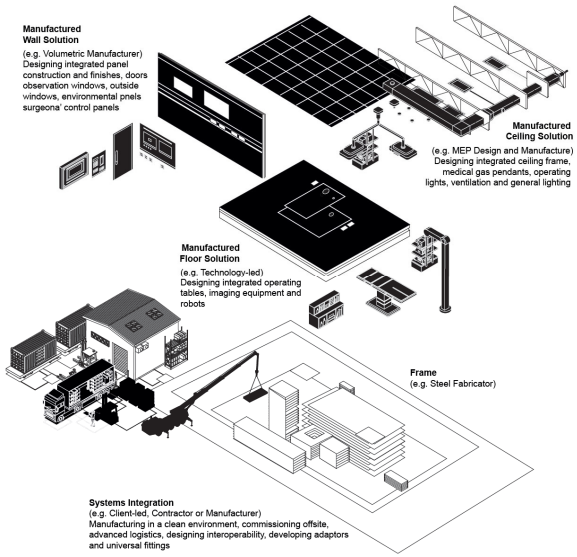
EuHPN European Health Property Network

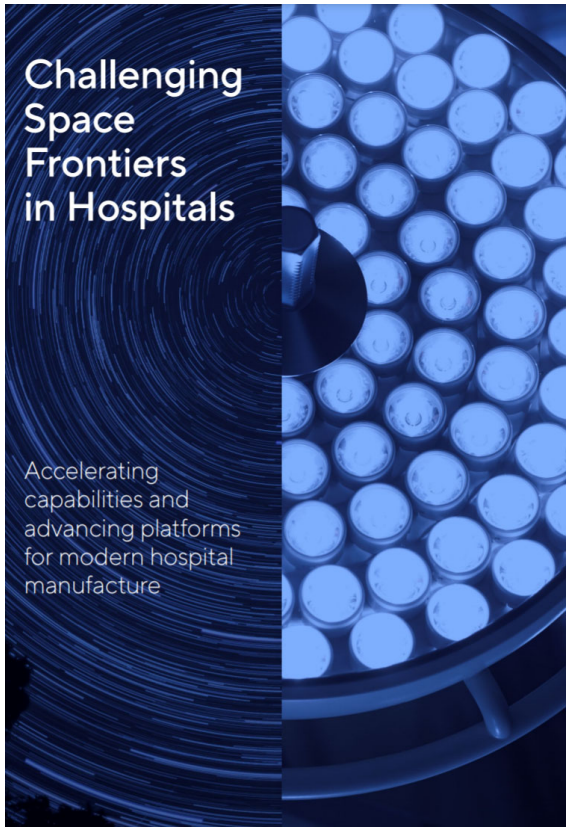
Rapid Assembly: Covid-19 in China (Huoshen Mountain Hospital 'Mount Fire God‘)

- Wuhan (and other cities in Hubei) Lockdown in effort to Quarantine the outbreak.
- 1,000 bed accommodation using a **rapidly deployed volumetric solution with integrated engineering service**.
- Rapid assembly in 10 days – including 30 intensive care units, medical equipment rooms, and quarantine wards.
- Modeled on Xiaotangshan Hospital (Beijing) – in response to 2003 SARS epidemic.
- State-owned enterprise. Political pressure. People's Liberation Army jurisdiction and management.

Tan Tan; Grant Mills; Jiqiang Hu; Eleni Papadonikolaki (2021) *Integrated Approaches to Design for Manufacture and Assembly: A Case Study of Huoshenshan Hospital to Combat COVID-19 in Wuhan, China*, Journal of Management in Engineering

ESRC Transforming Construction Research Project – Challenging Space Frontiers





Available at:
bit.ly/ChallengingSpaceFrontiersinHospitals-Report

https://youtu.be/FYTixxXE_KM

The Purpose

- Need to **develop capabilities** to increase the productivity, scalability and faster delivery of hospital theatre projects
- Existing manufactured, volumetric, component and traditional solutions are not **being challenged**
- **Make comparison with spacecraft system manufacture** to advance understanding of **fast-moving technologies, airtight assembly, logistics, innovation and integration**
- To research the **presumption for offsite in healthcare building** and advance DfMA
- To explore the capabilities, **business models and incentives** for accelerated pathways to offsite building manufacture and delivery
- To understand how manufactured, volumetric, component and traditional solutions can be found for this complex setting – then to **deliver efficiencies and increased quality**

The Problem

4.7m

Backlog of patient operations due to COVID-19

473 $ktCO_2$

Annual greenhouse gas emissions from operating theatres in NHS England (surgery)

Maldives

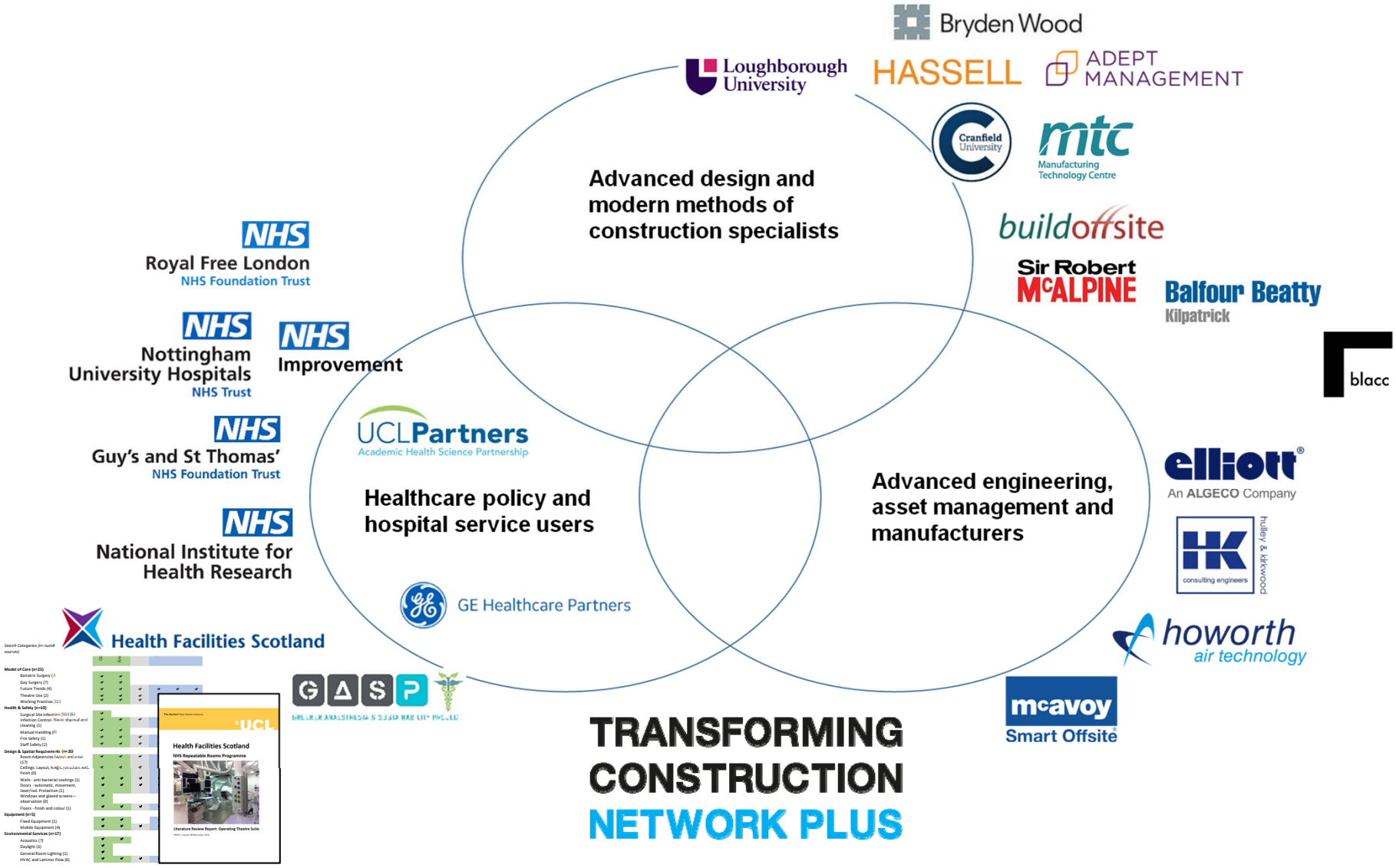
£0.5bn

Scale of the UK capital investment in Operating Theatres pre-COVID-19 (550 Theatres)

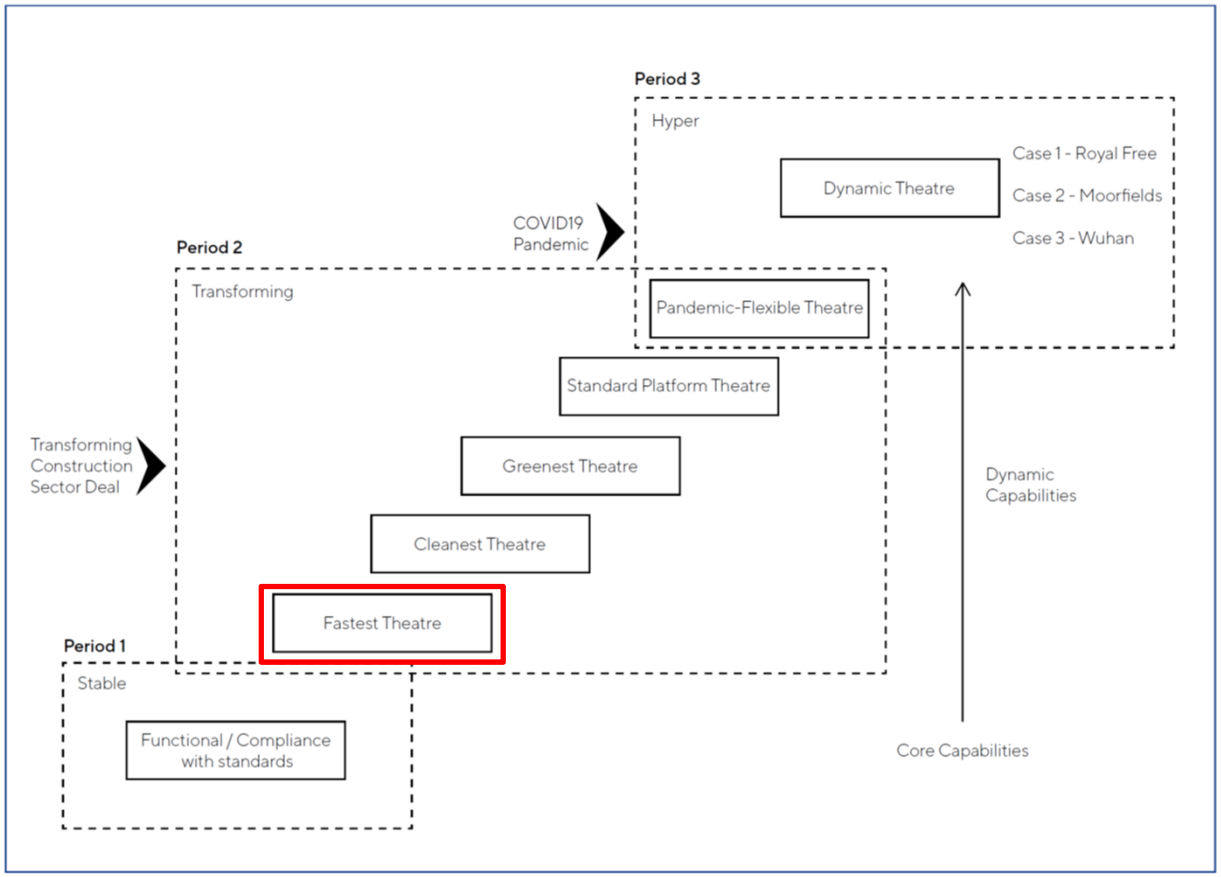
3,229

Operating theatres in England, with an operating cost of £4,800 per day for each

The Collaborators



The Research Process



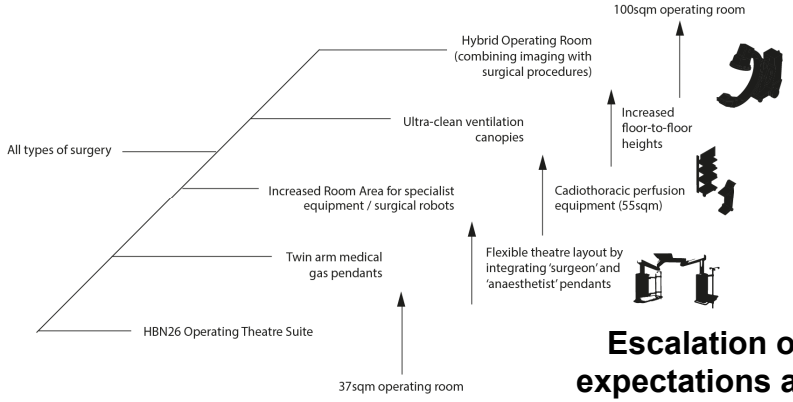
The stable, transforming and hyper periods that defined the sample period. Then the functional, fast, clean, green, standard platform and pandemic-flexible theatre capabilities explored in respose.

	Period 1 - Existing Stable Environment – Establishing the Baseline Need (June – September 2019)	Period 2 - Transformation Dynamic Environment (September 2019 – March 2020)	Period 3 - Regeneration Hyper Environment (March 2020 – June 2020)
Advanced modular designers			
Steven Tilkin (Bryden Wood)	SGM 1	SGM 4	
Joel Beaumont (Adept Management Limited)	SGM 1		
David Prangley (Adept Management Limited)	Quickest Theatre		
Xavier De Kestelier (Hassell Studio)	Quickest Theatre, SGM 2		
Susan Hone-Brookes (Manufacturing Technology Centre)	SGM 1, Cleanest Theatre, SGM 3		Case Moorfields
Charlie Foster (Manufacturing Technology Centre)	SGM 2	P22 IUK, WKSP	Case Moorfields
Richard Crosby (Blacc ltd)	SGM 2, Cleanest Theatre, SGM 3	Greenest Theatre, SGM 4	Case Moorfields
Aphrodite Bamboosy (Blacc ltd)	SGM 1		
Hina Lad (Penoyre & Prasad)		Int.	Case Moorfields
Lewis Parker (Kier / P22)	Int, SGM 3	Int. WKSP	
Stuart McArthur (Sir Robert McAlpine)		Int	
John Brady (Sir Robert McAlpine)		Greenest Theatre. SGM 4	
Other P22 Partners (SRM, Kier, Interserve, Vinci), Medical Architecture (n=6)		P22 IUK, WKSP	
Advanced engineering and manufacturers			
Donald Wood (Hulley and Kirkwood)	Quickest Theatre, SGM 2	Greenest Theatre, SGM 4	
Rebecca McCormack (Elliott / Algeco)	Quickest Theatre, SGM 2	Greenest Theatre, SGM 4	
James Cowell (Elliott / Algeco)	Quickest Theatre		Case Moorfields
Chris Hoggarth (Elliott / Algeco)	SGM 1, Quickest Theatre	Greenest Theatre, SGM 4	
Darrin Witcher (Elliott / Algeco)		Greenest Theatre, SGM 4, Int	Case Moorfields
Lee Bridges (BBK)	SGM 1, Quickest Theatre, SGM 2		
Gary McGuire (J3 / McGuire PBM)		Greenest Theatre, SGM 4	
Healthcare policy, services and users			
Martin Rooney (NHS Improvement)	Int, Cleanest Theatre, SGM 3	Greenest Theatre, SGM 4	
Jennifer Whinnett (Guy's and St Thomas' NHS FT)	SGM 2 [5]		
Dr Adbullahi Sheriff (GE Healthcare Partners)			
Ellie Richardson (Guys and StThomas NHS FT)	Quickest Theatre, Int	Greenest Theatre. SGM 4, Int.	
Timothy Gaymer (Royal Free London NHS FT)	Quickest Theatre, SGM 2	Greenest Theatre, SGM 4	Case Royal Free
Susan Grant (NHS Health Facilities Scotland)	SGM 2	SGM 4	
Gordon Stewart (Health Facilities Scotland)	SGM 1		
Alyson Prince (UCLH Infection Control Nurse)	Int, Cleanest Theatre, SGM 3		
Jonny Groome (Greener Anaesthesia)		Greenest Theatre, SGM 4	
Laura Wilkes (Royal Free London NHS FT)	Quickest Theatre		
Miliana Dotcheva (Royal Free London NHS FT)	Quickest Theatre		
Laura Brewester (Moorfields NHS FT)		Case Moorfields	
Mariepi Manoliscylwi (Moorfields NHS FT)		Case Moorfields	
Paul Foster (Moorfields NHS FT)			Case Moorfields
Other Case Wuhan (n=20)			Case Wuhan
Other Case Royal Free, 18/02/20 - 03/03/20 (n=17)			Case Royal Free
Other Case Moorfields (UCLH, Moorfields, UCL) 04/02/20 - 09/06/20 (n=16)			Case Moorfields
Researchers			
Dr Grant Mills (UCL construction and project manager)	All	All	All
Dr Chris Goodier (Loughborough structural engineer)	Cleanest Theatre, SGM 3		
Dr Jennifer Kingston (Cranfield spacecraft engineer)	SGM 1, Quickest Theatre, SGM 2	Greenest Theatre, SGM 4	
Phil Astley (UCL Architect and Health Planner)	Cleanest Theatre, SGM 3	Greenest Theatre, SGM 4	Case Royal Free
Anne Symons (UCL Healthcare Architect)	All	All.	All, Case Moorfields, Case Royal Free
Tan Tan (UCL Architect)		SGM 4	Case Wuhan
Chris Sherwood (UCL Healthcare	Quickest Theatre		

Alignment of Incentives

	Period 1 - Existing Stable Environment – Establishing the Baseline Need	Period 2 - Transformation Dynamic Environment	Period 3 - Regeneration Hyper Environment
Modular Theatre Design, Manufacture and Assembly Integrators	Traditional **sequencing is not providing effective delivery**	**Supply chain innovation requires strong client leadership**, funded R&D and a stable long-term programme that provides a commitment to capability building	A rapid response requires resilience planning and scalable solutions that are flexible and quick to integrate with operation
Theatre Technology Driver, Engineer and Advanced Manufacturer	**Modular components could be designed, manufactured and assembled to address interfaces**	**The wider supply chain can innovate to achieve sustainability, efficiency and flexibility. Out of date standards and risk transfers (rather than allocation) constrains this innovation**	**Lack of early specialist supplier engagement prevents innovation in engineering, asset management and manufacture**
Healthcare Policy and Hospital Theatre Operator and Service Users	Stakeholder requirements and disruptive design iteration. **Digital design mock-ups and evidence-based post-project learning will enable consultation and agreement**	Wider programme level interdisciplinary capability pools to set dynamic sustainability, innovation, cleanliness and efficiency targets. **Research must drive standards and supply chains must be engaged to address potential operational failures.**	Decision making must be fast, but may not consider all the options or engage all the appropriate specialists. **Evidence is not always available. Research must be rapidly deployable. Strong and aligned purpose and experience can drive project success.**
Interdisciplinary Research (including spacecraft engineering)	Need for clear functional definition, support for evidence-based design in requirements definition and future foresight on innovative solutions	Space engineering **advances in systems thinking, standards development, real-time sensing and advanced integration**. Value of experienced healthcare researchers	**Innovative technologies are driving flexibility (de-coupled from the buildings fabric).** Buildings must be procured, designed, manufactured and assembled according to primary, secondary and tertiary layers.

Complex Systems Integration

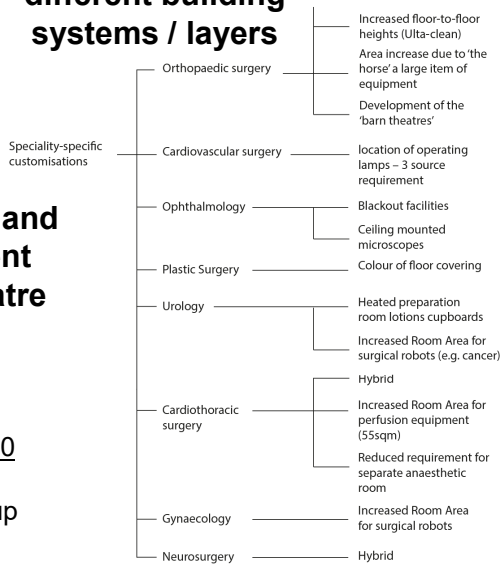


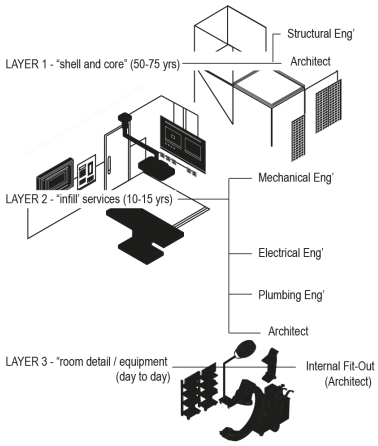
Expanding number of systems and unique stakeholder requirements

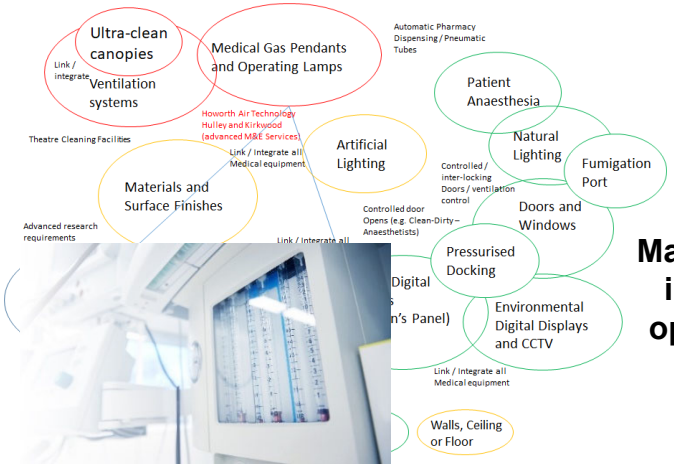
1. Flexible Gas Pendant	2. Rigid Gas Pendant	3. Articulated Single Arm Pendant	4. Articulated Twin Arm Pendants
			
1980s	1990s	2000s	2010s
Anaesthetist Architect Mechanical Services Engineer	Anaesthetist Surgeon Architect Mechanical Services Engineer Electrical Services Engineer	Medical and Nursing Staff Trust Equipment Manager Architect Mechanical Services Engineer Electrical Services Engineer Structural Engineer Main Contractor Mechanical Sub- contractor Pendant Manufacturer	Medical and Nursing Staff Trust Equipment Manager Medical Physics Estates Department Architect Mechanical Services Engineer Electrical Services Engineer Structural Engineer Main Contractor Mechanical Sub- contractor Pendant Manufacturer Examination Lamp Manufacturer

Escalation of expectations and requirements

Clinical-specialist specific theatres and their impact on different building systems / layers







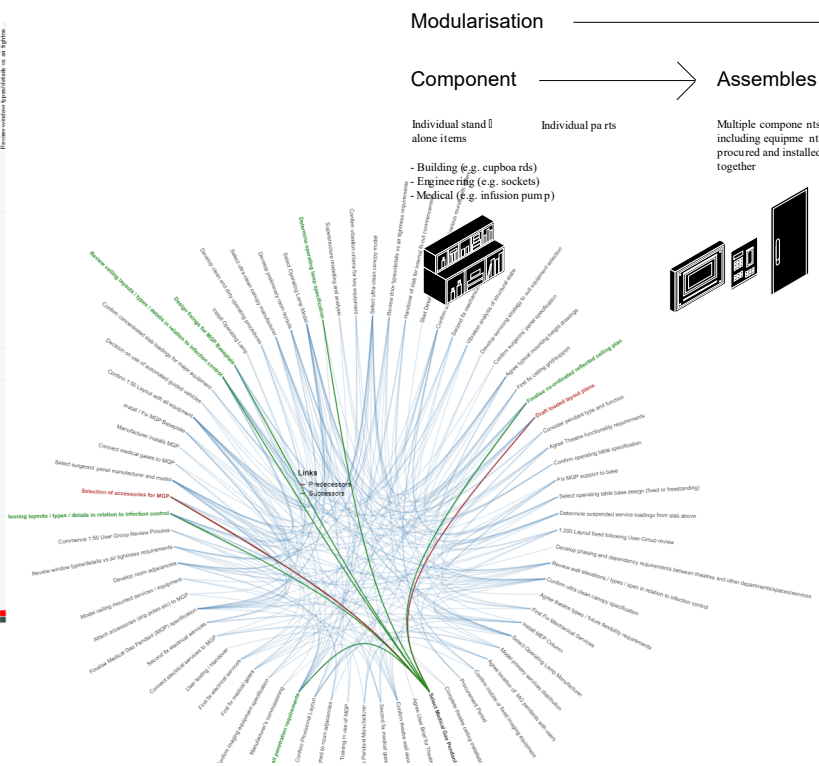
Many complex and interdependent operating theatre systems

SAGETECH MEDICAL EQUIPMENT

Example - Anaesthetic gases are 2540 times more warming than CO_2 while others remain in the troposphere for up to 110 years.

Complex Systems Integration

We are directly addressing **modularity, outsourcing, systems integration, organisational design, project planning and process improvement** (e.g. high areas of technology risk, anticipate integration issues and to predict interactions, adapt and identify alternatives).



Complex Systems Integration

WP1 - STAKEHOLDER / USER GROUP ENGAGEMENT

Design/User Group 1		Design/User Group 2	
Client brief		*Agree User Groups*	
Theatre Functionality		*Agree planning of theatre / Phasing of Dependencies*	
1	Develop clean and dirty operating procedures	3	Develop clean and dirty operating procedures
2	Decision on use of automated guided vehicles	2	Decision on use of automated guided vehicles
3	Confirm pressure regime aligned to room adjacencies		X
Room Adjacencies / Room Layout		*Agree Theatre Type / Types / Future Flexibility*	
4	Confirm mobile or fixed imaging equipment		X
Consider Pendant Type / Function		*Equipment Use*	
5	Select operating table base design (fixed or freestanding)		X
6	Confirm ultra-clean canopy services requirements	1	Confirm ultra-clean canopy services requirements
7	Confirm vibration criteria for key equipment		X
Provisional Layout			
1:50 Process		*Requirement 1:50*	
11	Agree location of MG pendants with users		X
32	Confirm operating table specification		X
33	Confirm imaging equipment specification		X
16	Selection of accessories for MGP		X
22	X	35	Agree typical mounting height drawings

WP2 - SCHEME DESIGN

Design/User Group 1		Design/User Group 2	
8	Superstructure modelling and analysis	9	Superstructure modelling and analysis
9	Model primary services distribution	5	Model primary services distribution
Scheme Design			
10	1:200 Layout fixed following User Group review	4	1:200 Layout fixed following User Group review
13	Develop servicing strategy to suit equipment selection	12	Develop servicing strategy to suit equipment selection
14	Model ceiling mounted services / equipment	13	Model ceiling mounted services / equipment
Loaded Layout Plan		*Plan Department Layout*	
		Workshop to Agree Equipment	
15	Select Medical Gas Pendant Model		X
18	Review wall elevations / types / spec in relation to infection control	26	Review wall elevations / types / spec in relation to infection control
19	Review flooring layouts / types / details in relation to infection control	25	X
20	Review ceiling layouts / types / details in relation to infection control	24	Review ceiling layouts / types / details in relation to infection control
21	Confirm theatre wall elevations	37	Confirm theatre wall elevations
23	Confirm ultra clean canopy specification		X
1:50 Sign Off			
	WP1	40	Selection of accessories for MGP
	WP1	8	Confirm pressure regime aligned to room adjacencies

WP3 - DETAILED DESIGN

Design/User Group 1		Design/User Group 2	
17	Determine operating lamp specification		X
22	Agree typical mounting height drawings		X
24	Confirm 1:50 Layout with all equipment	34	X
25	Finalise Medical Gas Pendant (MGP) specification	29	Finalise Medical Gas Pendant (MGP) specification
31	Determine suspended service loadings from slab above	10	Determine suspended service loadings from slab above
34	Vibration analysis of structural slabs	11	Vibration analysis of structural slabs
36	Confirm concentrated slab loadings for major equipment	6	X
37	Confirm wall penetration requirements	38	Confirm wall penetration requirements
41	Finalise co-ordinated reflected ceiling plan	36	Finalise co-ordinated reflected ceiling plan
40	Confirm surgeons' panel specification	31	Confirm surgeons' panel specification
39	Review door types/details vs air tightness requirements	28	Review door types/details vs air tightness requirements
38	Review window types/details vs air tightness requirements	27	Review window types/details vs air tightness requirements
	WP2	33	Confirm ultra clean canopy specification
	WP2		Review flooring layouts / types / details in relation to infection control
	WP1	17	Select operating table base design (fixed or freestanding)
	WP1	30	Confirm imaging equipment specification
	WP2	19	Select Medical Gas Pendant Model
	WP1	23	Confirm mobile or fixed imaging equipment
		Comment 1:50 Design	
	X	21	Select Operating Lamp Model
	WP1	22	Agree location of MG pendants with users
	X	39	Design fixings for MGP Baseplate
	WP1	32	Confirm operating table specification
	WP1	7	Confirm vibration criteria for key equipment
		Plan Theatre Layout	

WP4 - PROCUREMENT AND SUPPLY CHAIN DESIGN / MANUFACTURE

Design/User Group 1		Design/User Group 2	
12	Select Medical Gas Pendant Manufacturer	18	Select Medical Gas Pendant Manufacturer
35	Design fixings for MGP Baseplate		X
27	Select ultra-clean canopy manufacturer	14	Select ultra-clean canopy manufacturer
28	Select ultra-clean canopy model	15	Select ultra-clean canopy model
30	Select surgeons' panel manufacturer and model	16	Select surgeons' panel manufacturer and model
29	Select Operating Lamp Manufacturer	20	Select Operating Lamp Manufacturer
26	Select Operating Lamp Model	21	X

WP5 - CONSTRUCTION / INSTALLATION

Design/User Group 1		Design/User Group 2	
Procure			
42	Handover of slab for internal fit-out commencement	41	Handover of slab for internal fit-out commencement
43	Fix MGP support to base	43	Fix MGP support to base
44	First fix electrical services	46	First fix electrical services
45	First Fix Mechanical Services	47	First Fix Mechanical Services
46	First fix medical gases	45	First fix medical gases
47	Install / Fix MGP Baseplate	42	Install / Fix MGP Baseplate
48	First fix ceiling grid/support	44	First fix ceiling grid/support
MEP Collision			
49	Second fix electrical services	51	Second fix electrical services
50	Second fix medical gases	50	Second fix medical gases
51	Connect medical gases to MGP		X
52	Connect electrical services to MGP	54	Connect electrical services to MGP
53	Complete theatre ceiling installation	48	Complete theatre ceiling installation
54	Manufacturer installs MGP	49	Manufacturer installs MGP
55	Install Operating Lamp	52	Install Operating Lamp
56	Attach accessories (drip poles etc) to MGP	56	Attach accessories (drip poles etc) to MGP
	X		Second fix mechanical services

WP6 - COMMISSIONING AND HANDOVER

Design/User Group 1		Design/User Group 2	
57	MGP Manufacturer's commissioning	57	MGP Manufacturer's commissioning
58	Training in use of MGP	58	Training in use of MGP
Ops Warranty			
59	User testing / Handover	59	User testing / Handover
	WP5	55	Connect medical gases to MGP

Significant sequencing differences between two groups

Complex Systems Integration

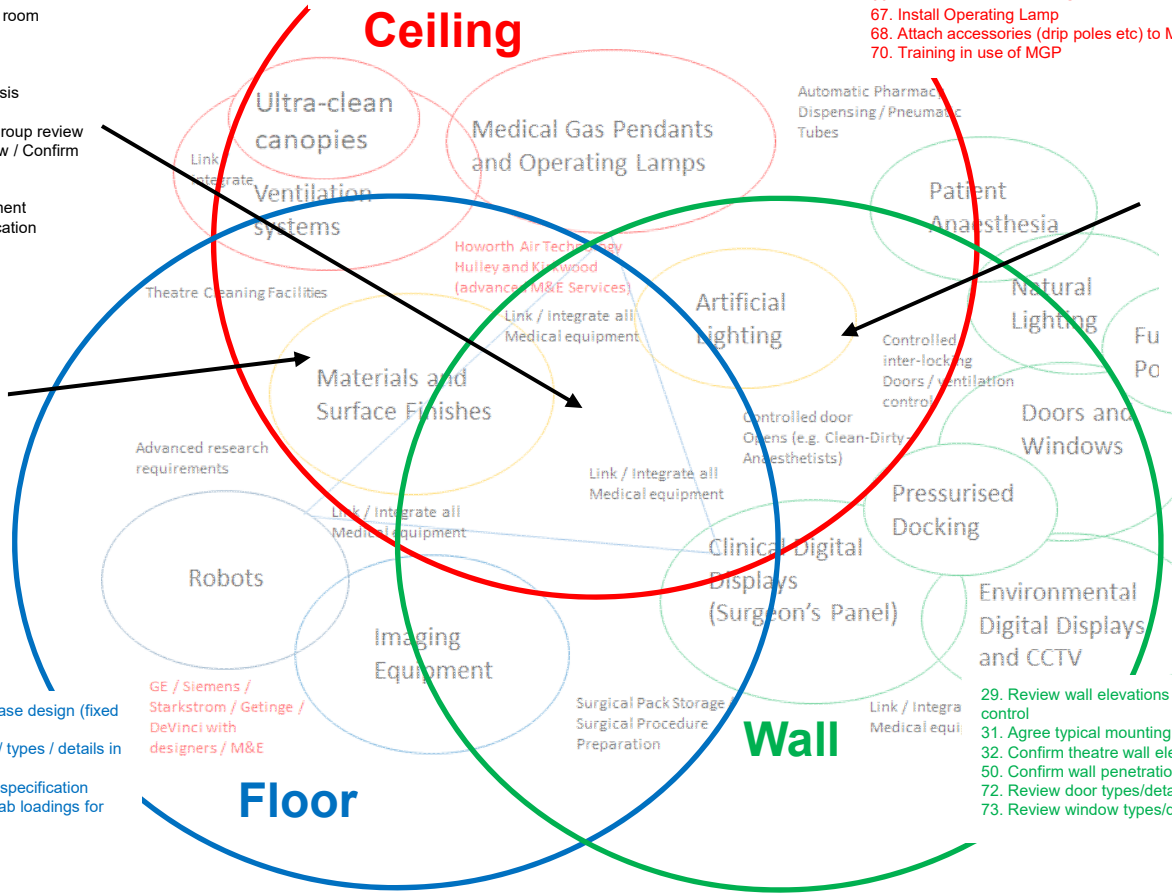
1. Agree User Brief for Theatre(s)
2. Agree Theatre Functionality Requirements
3. Agree Theatre Types / future flexibility requirements
4. Start Detailed User Group Workshops
5. Develop Phasing and Dependency Requirements
6. Develop clean and dirty operating procedures
9. Develop Preliminary Room Layouts
10. Confirm pressure regime aligned to room adjacencies
11. Develop Room Adjacencies
16. Confirm Provisional Layout
17. Superstructure modelling and analysis
18. Model primary services distribution
19. 1:200 Layout fixed following User Group review
20. Commence 1:50 User Group Review / Confirm 1:50 Layout with all equipment
25. Draft Loaded / Layout Plans
36. Confirm 1:50 Layout with all Equipment
45. Confirm imaging equipment specification
53. Handover of slab for internal fit-out commencement
55. First fix electrical service
69. Manufacturer's commissioning
71. User testing / Handover

8. Consider Pendant Type and Function
12. Confirm ultra clean canopy specification
22. Select Medical Gas Pendant Manufacturer
24. Model ceiling mounted services / equipment
27. Determine operating lamp specification
28. Select Medical Gas Pendant Model
30. Review ceiling layouts / types / details in relation to infection control
34. Confirm ultra-clean canopy services requirements
37. Select ultra-clean canopy model
38. Select Operating Lamp Model
39. Select Operating Lamp Manufacturer

40. Finalise Medical Gas Pendant (MGP) specification
41. Select ultra-clean canopy manufacturer
47. Design fixings for MGP Baseplate
49. Finalise co-ordinated reflected ceiling plan
52. Fix MGP support to base
57. Install / Fix MGP Baseplate
58. First fix ceiling grid/support
59. Install MEP Column
63. Connect medical gases to MGP
64. Connect electrical services to MGP
65. Complete theatre ceiling installation
66. Manufacturer installs MGP
67. Install Operating Lamp
68. Attach accessories (drip poles etc) to MGP
70. Training in use of MGP

23. Develop servicing strategy to suit equipment selection
35. Select surgeons' panel manufacturer and model
42. Confirm surgeons' panel specification
44. Determine suspended service loadings from slab above
51. Procurement Period
54. First fix medical gases
56. First fix Mechanical Services
60. Second fix medical gases
61. Second fix electrical services
62. Second fix mechanical services

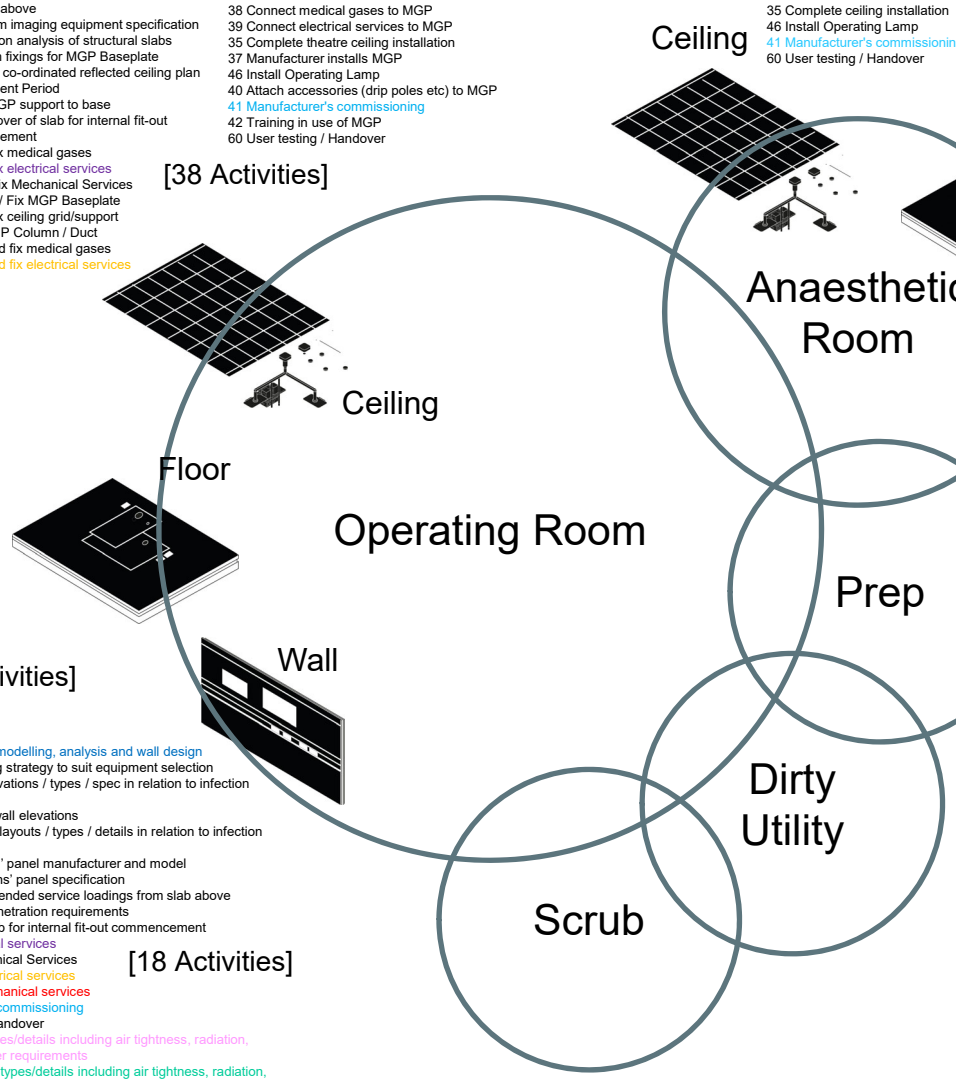
13. Confirm mobile or fixed imaging equipment
15. Confirm vibration criteria for key equipment
21. Agree location of MG pendants with users
46. Vibration analysis of structural slabs



14. Select operating table base design (fixed or freestanding)
33. Review flooring layouts / types / details in relation to infection control
43. Confirm operating table specification
48. Confirm concentrated slab loadings for major equipment

29. Review wall elevations / types / spec in relation to infection control
31. Agree typical mounting height drawings
32. Confirm theatre wall elevations
50. Confirm wall penetration requirements
72. Review door types/details vs air tightness requirements
73. Review window types/details vs air tightness requirements

Complex Systems Integration



Consider Pendant Type and Function
47 Confirm ultra clean canopy specification
56 Confirm mobile or fixed imaging equipment
14 Confirm vibration criteria for key equipment
17 Superstructure modelling, analysis and wall design
18 Model primary services distribution
24 Agree location of MG pendants with users
22 Select Medical Gas Pendant Manufacturer
6 Develop servicing strategy to suit equipment selection
7 Model ceiling mounted services / equipment
36 Selection of accessories for MGP
43 Determine operating lamp specification
23 Select Medical Gas Pendant Model
9 Review ceiling layouts / types / details in relation to infection control
48 Confirm ultra-clean canopy services requirements
52 Select surgeons' panel manufacturer and model
50 Select ultra-clean canopy model
45 Select Operating Lamp Model
44 Select Operating Lamp Manufacturer
21 Finalise Medical Gas Pendant (MGP) specification
49 Select ultra-clean canopy manufacturer
51 Confirm surgeons' panel specification

13 Determine suspended service loadings from slab above
55 Confirm imaging equipment specification
15 Vibration analysis of structural slabs
25 Design fixings for MGP Baseplate
8 Finalise co-ordinated reflected ceiling plan Procurement Period
30 Fix MGP support to base
59 Handover of slab for internal fit-out commencement
27 First fix medical gases
28 First fix electrical services
29 First Fix Mechanical Services
26 Install / Fix MGP Baseplate
34 First fix ceiling grid/support
Install MEP Column / Duct
31 Second fix medical gases
32 Second fix electrical services

33 Second fix mechanical services
38 Connect medical gases to MGP
39 Connect electrical services to MGP
35 Complete theatre ceiling installation
37 Manufacturer installs MGP
46 Install Operating Lamp
40 Attach accessories (drip poles etc) to MGP
41 Manufacturer's commissioning
42 Training in use of MGP
60 User testing / Handover

[38 Activities]

17 Superstructure modelling, analysis and wall design
43 Determine operating lamp specification
9 Review ceiling layouts / types / details in relation to infection control
45 Select Operating Lamp Model
44 Select Operating Lamp Manufacturer
8 Finalise co-ordinated reflected ceiling plan Procurement Period
28 First fix electrical services
29 First Fix Mechanical Services
32 Second fix electrical services
33 Second fix mechanical services
35 Complete ceiling installation
46 Install Operating Lamp
41 Manufacturer's commissioning
60 User testing / Handover

[15 Activities]

14 Confirm vibration criteria for key equipment
17 Superstructure modelling, analysis and wall design
20 Review flooring layouts / types / details in relation to infection control
15 Vibration analysis of structural slabs
16 Confirm concentrated slab loadings for major equipment
59 Handover of slab for internal fit-out commencement
First fix plumbing
Second fix plumbing

[8 Activities]

17 Superstructure modelling, analysis and wall design
6 Develop servicing strategy to suit equipment selection
10 Review wall elevations / types / spec in relation to infection control
4 Agree typical mounting height drawings
5 Confirm wall elevations
19 Confirm wall penetration requirements Procurement Period
59 Handover of slab for internal fit-out commencement
27 First fix medical gases
28 First fix electrical services
29 First Fix Mechanical Services
First Fix Plumbing
31 Second fix medical gases
32 Second fix electrical services
33 Second fix mechanical services
Second fix plumbing services
41 Manufacturer's commissioning
60 User testing / Handover
11 Review door types/details including air tightness, radiation, fire, sound and laser requirements
12 Review window types/details including air tightness, radiation, fire, sound and laser requirements

[19 Activities]

56 Confirm mobile or fixed imaging equipment
54 Select operating table base design (fixed or freestanding)
14 Confirm vibration criteria for key equipment
17 Superstructure modelling, analysis and wall design
20 Review flooring layouts / types / details in relation to infection control
53 Confirm operating table specification
55 Confirm imaging equipment specification
15 Vibration analysis of structural slabs
16 Confirm concentrated slab loadings for major equipment
59 Handover of slab for internal fit-out commencement
28 First fix electrical services
Install MEP Column / Duct
32 Second fix electrical services
33 Second fix mechanical services
41 Manufacturer's commissioning

[15 Activities]

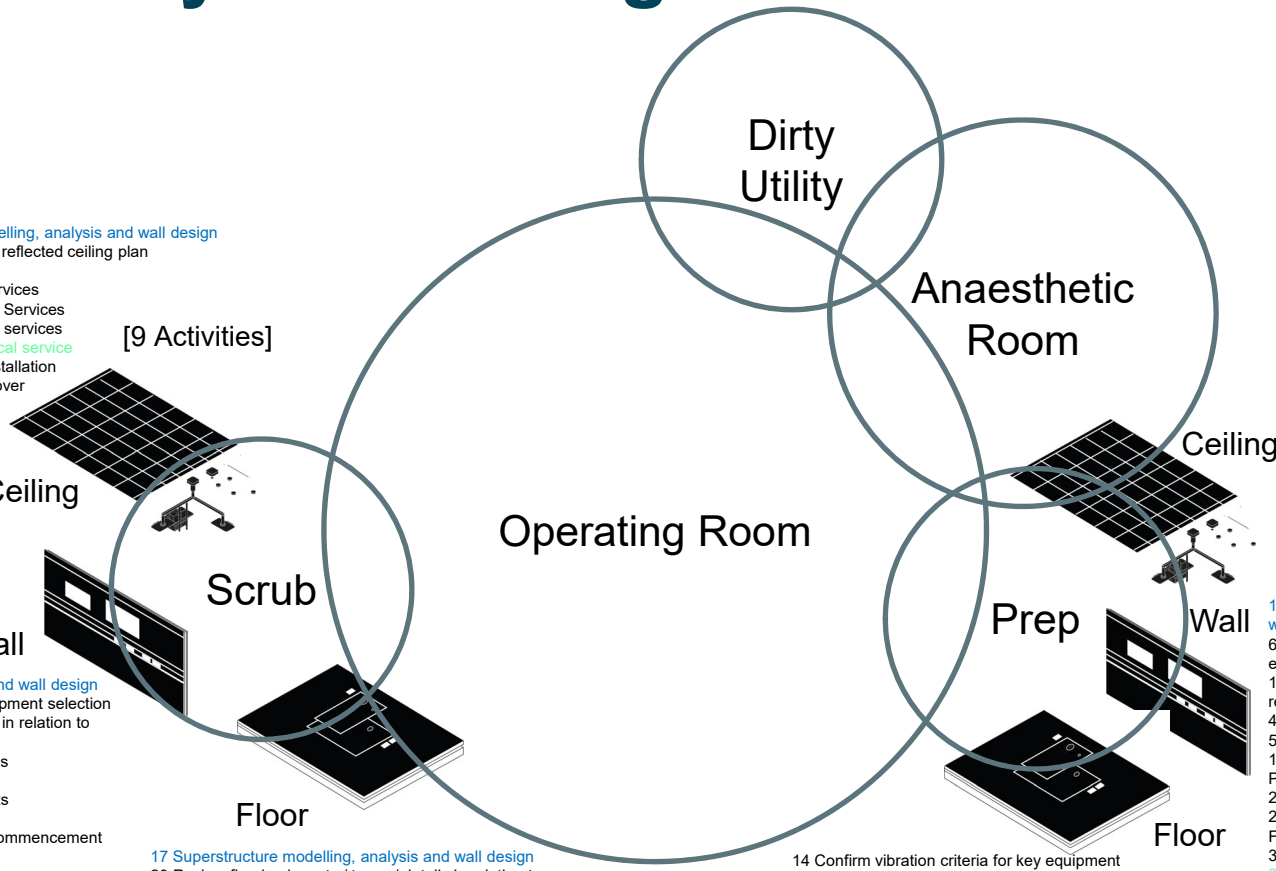
17 Superstructure modelling, analysis and wall design
6 Develop servicing strategy to suit equipment selection
10 Review wall elevations / types / spec in relation to infection control
5 Confirm theatre wall elevations
20 Review flooring layouts / types / details in relation to infection control
52 Select surgeons' panel manufacturer and model
51 Confirm surgeons' panel specification
13 Determine suspended service loadings from slab above
19 Confirm wall penetration requirements
59 Handover of slab for internal fit-out commencement
28 First fix electrical services
29 First Fix Mechanical Services
32 Second fix electrical services
33 Second fix mechanical services
41 Manufacturer's commissioning
60 User testing / Handover
11 Review door types/details including air tightness, radiation, fire, sound and laser requirements
12 Review window types/details including air tightness, radiation, fire, sound and laser requirements

[18 Activities]

General
Agree User Brief for Operating Room
Agree Operating Room adjaciences
Agree Operating Room Types / future flexibility requirements
Start Detailed User Group Workshops
Develop Phasing and Dependency Requirements
57 Develop clean and dirty operating procedures
Develop Preliminary Room Layouts
3 Confirm pressure regime aligned to room adjacencies
Develop Room Adjacencies
18 Model primary services distribution
1 1:200 Layout fixed following User Group review
2 Commence 1:50 User Group Review / Confirm 1:50 Layout with all equipment
Draft Loaded / Layout Plans
Confirm 1:50 Layout with all Equipment

[15 Activities]

Complex Systems Integration



17 Superstructure modelling, analysis and wall design
8 Finalise co-ordinated reflected ceiling plan
Procurement Period
28 First fix electrical services
29 First Fix Mechanical Services
32 Second fix electrical services
33 Second fix mechanical service
35 Complete ceiling installation
60 User testing / Handover

[9 Activities]

17 Superstructure modelling, analysis and wall design
6 Develop servicing strategy to suit equipment selection
10 Review wall elevations / types / spec in relation to infection control
4 Agree typical mounting height drawings
5 Confirm wall elevations
19 Confirm wall penetration requirements
Procurement Period
59 Handover of slab for internal fit-out commencement
28 First fix electrical services
29 First Fix Mechanical Services
First Fix Plumbing
32 Second fix electrical services
33 Second fix mechanical service
Second fix plumbing services
60 User testing / Handover
11 Review door types/details including air tightness, radiation, fire, sound and laser requirements
12 Review window types/details including air tightness, radiation, fire, sound and laser requirements

[18 Activities]

17 Superstructure modelling, analysis and wall design
20 Review flooring layouts / types / details in relation to infection control
15 Vibration analysis of structural slabs
16 Confirm concentrated slab loadings for major equipment
59 Handover of slab for internal fit-out commencement
First fix plumbing
Second fix plumbing

[7 Activities]

14 Confirm vibration criteria for key equipment
17 Superstructure modelling, analysis and wall design
20 Review flooring layouts / types / details in relation to infection control
15 Vibration analysis of structural slabs
16 Confirm concentrated slab loadings for major equipment
59 Handover of slab for internal fit-out commencement
First fix plumbing
Second fix plumbing

[9 Activities]

[10 Activities]

17 Superstructure modelling, analysis and wall design
8 Finalise co-ordinated reflected ceiling plan
Procurement Period
28 First fix electrical services
29 First Fix Mechanical Services
32 Second fix electrical services
33 Second fix mechanical service
35 Complete ceiling installation
41 Manufacturer's commissioning
60 User testing / Handover

17 Superstructure modelling, analysis and wall design
6 Develop servicing strategy to suit equipment selection
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Procurement Period
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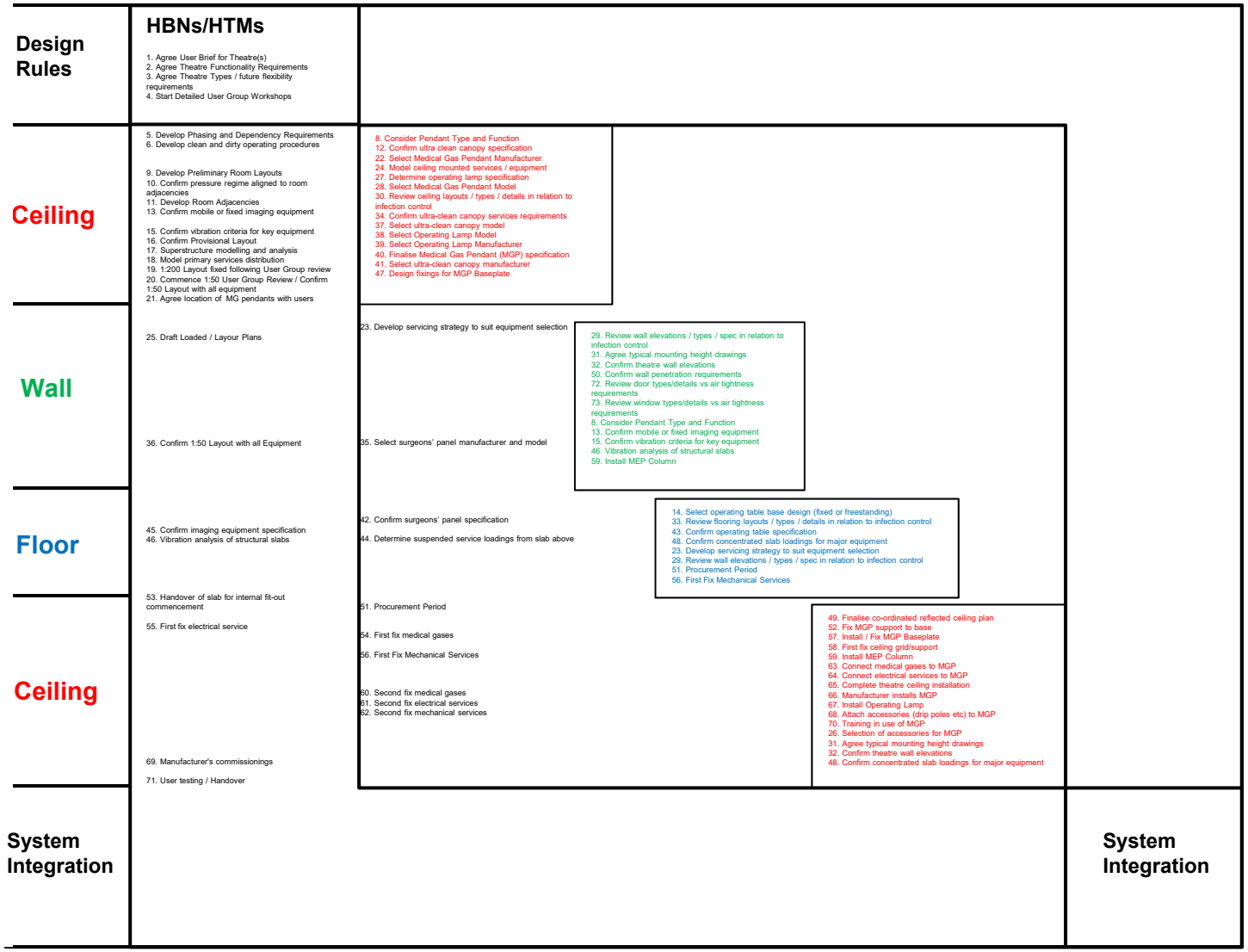
Second fix plumbing services
41 Manufacturer's commissioning
60 User testing / Handover
11 Review door types/details including air tightness, radiation, fire, sound and laser requirements
12 Review window types/details including air tightness, radiation, fire, sound and laser requirements

[17 Activities]

Complex Systems Integration

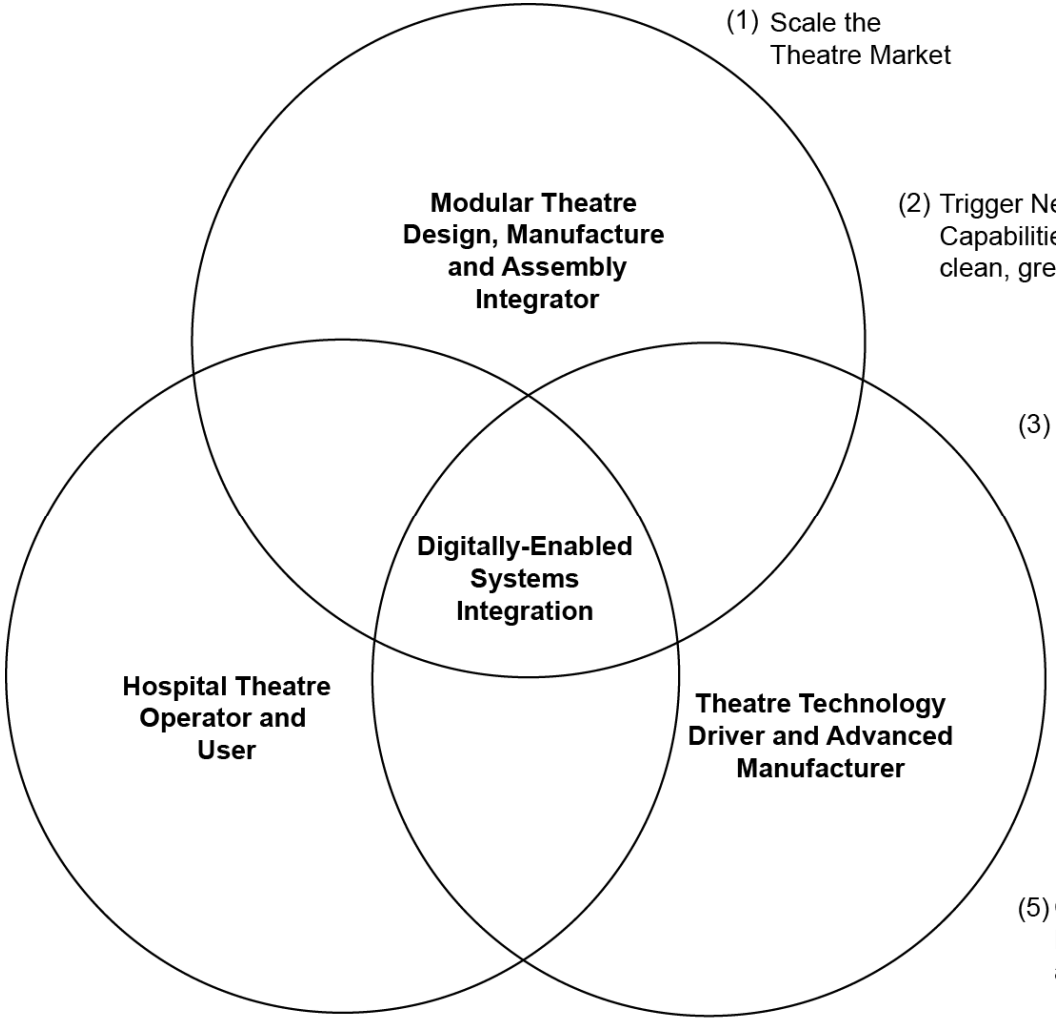


Findings

Maturity 

	Project Platform	Supply Chain Platform	Wider-Industry Platform
Delivery Model	**Project-based delivery model** creates core rigidity. Project procurement uses existing capabilities and few innovation triggers and limited learning of lessons	**Existing supply chain** delivery model creates core rigidity. Innovation is limited due to a focus on existing arrangements and capabilities	**Innovation created through setting targets with a wider capability pool**. Programme outcomes are prioritised. Early supplier engagement. Risks are allocated, responsibilities shared and teams incentivised
Innovation	**Closed collaboration**. Procurement constraints imposed on manufacturers and protection of supply chains	**Somewhat open collaboration**. Both cooperation and competition dynamics between contractors. Highly competitive and transactional with innovation outside of the framework controlled and prevented	**Open collaboration**. Uncertainty reveals need for rapid, open and collaborative learning platforms. Innovative interfaces between equipment manufacturers, suppliers and integrators
Capabilities	**Capability acquisition is triggered by project funding and is within the firm**. Volatility in demand and fluctuations in funding do not stimulate innovative capabilities. Lack of scale prevents capability development between firms	**Within a framework of supply chain partners there is capability building and co-evolutionary dynamics**	**Ecosystem-wide capabilities development and incentivisation to innovate**. A flexible and resilient response. Rapid procurement of the most capable teams to integrate design and engineering.
Governance	**Projects are fragmented and misaligned**. Client leadership at a local level with few programme functions	**Programme governance to stimulate supply chain innovation** / learning and strong relationships	**Strong ecosystem through dynamic leadership and governance.** Interdisciplinary cluster teams and empowered/incentivised collaborative working
Digital Systems Integration	**Traditional design and construction creates sequences that are preventing innovation**	**Repeatable design and BIM standards are retained by framework partners.** Constrained learning	**Digitally-enabled design integration facilitated by advanced planning,** the introduction of layers and a kit-of-parts. All parties understand the need for a modular system and conform to those rules

Recommendations



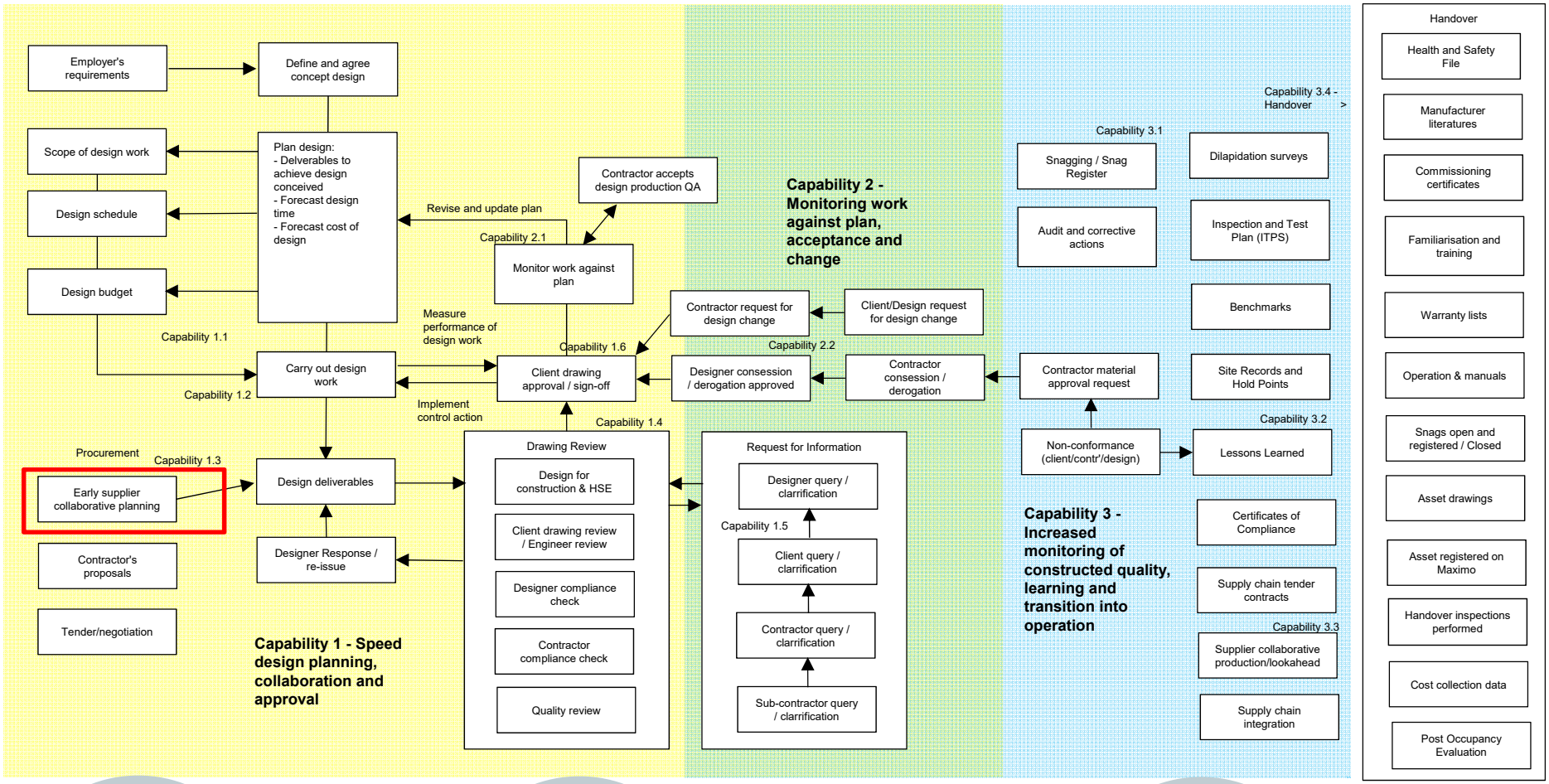
(1) Scale the Theatre Market

(2) Trigger New Dynamic Capabilities (e.g. fast, clean, green, and flexible)

(3) Create a Modular Theatre Ecosystem and Modular Cluster

(4) Integrate the Procurement of Major Items of Medical Equipment with Modular Theatre Ecosystem and Modular Cluster

(5) Create a Dynamic and Multi-sided Platform and Delivery Model



Outstanding design deliverables predicting production failure

328 design predictors, that led to 21 failures

Outstanding works predicting construction failure

28 production predictors (compounded with design predictors and failures, that led to 49 failures, and

5-10% CAPEX saving before handover, through the reduction of rework, waste and correction of defects

10 operation predictors that led to 1 defect, but also 1914 corrective maintenance events

Late Handover predicting operational failure

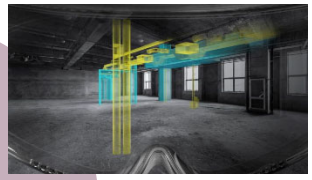
£50m every 5 years
Project slippage costs

3-20%pa
OPEX cost saving, through better consideration of whole life quality

What next?

- **Continued collaborative working** with advanced design and MMC, engineering, asset management and manufacturers, healthcare policy, innovative hospital services and users, and Integrators.
  - **Interdisciplinary design capabilities** - component and sub-assemblies level
  - **Advanced cluster** - to manage interfaces and integrate walls, ceilings and floor (e.g. panels, finishes, doors, windows and controls, ceiling frame, medical gas pendants, ventilation, general and operating lights, operating tables, imaging equipment and robots)
  - **Advanced digitally-enabled design integration -** The information in design is growing, making it difficult for one person to coordinate. Interfacing is complex and so getting the right information to the right place at the right time is a major challenge. The chances of error are growing as a result, unless advanced interdisciplinary capabilities are harnessed.

XYZ – Augmented Reality



Construction configuration / error reduction tool in complex hospital settings

NHS UCLH / Moorfield

Modular component for eye hospital diagnostic hubs

MACE IUK ICIF Transforming Construction Demonstrators

AEC Production Control Room