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Full Paper

Driving Innovation in Healthcare Design: The case of an interdisciplinary co-design process for a new rapid virtual diagnostics hub for eyes

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Abstract: There is a need to advance the way we design healthcare facilities to overcome the reliance on outdated healthcare building design standards. We investigate the reconfiguration of eyecare and the use of virtual diagnostic hubs to respond to the patient backlog created by COVID-19. Ophthalmology, the busiest UK NHS outpatient specialty (7.9 million episodes; 2018-19), is perfectly suited to providing a testbed for rapid, research-driven innovation. We show how research in the built environment can better inform clinical and technological advancement in rapid diagnostics, and show how an empty commercial real estate space can be repurposed for healthcare. A clinically-led case study is described which brings together various disciplines (service design, architecture, engineering and modelling expertise) to contribute to three unique building configurations which were devised and tested, with 1,000 patients visiting the site for care under each of the three iterations of the building layout design. Circa ~ 30 staff were involved in the interdisciplinary co-design process to encourage an innovative approach to equipment configuration, layout design and an emerging scientific evidence-base. We offer up a conceptualization of an evidence-based co-production process that optimized safety, efficiency of patient movement and staff satisfaction through iterative dialogues.

Keywords: Action-Research, Co-design, Evidence-based design, Interdisciplinary

1. Introduction

There is increased recognition of the need to improve the efficiency and effectiveness of health systems and to modernize through investments in new buildings, diagnostics and technology (DHSC, 2019). This will require the utilization, integration and development of interdisciplinary evidence from domains as diverse as economics, evidence-based medicine, engineering, operations management and design. Elf et al. (2015) emphasize architects, clients, clinicians and nurses who must join with policymakers, funders, planners and operations managers to agree actions based on diverse evidence bases, capabilities and methodologies. Critical is clinical leadership in the co-produce evidence to support whole-system reconfiguration (Limb 2013a, 2013b and Barratt and Raine, 2012), but also an interdisciplinary approach (Mills et al. 2015 and Erskine et al., 2019).

This work will show how interdisciplinary design has added value in three fundamental ways. First, in "building bridges" through the exchange of viewpoints between existing functional disciplines using an adaptive and agile design approach to modelling and prototyping physical diagnostic hub for eyes. Second, it documents alternative theoretical viewpoints, and third, it describes how these disciplinary boundaries were transcended through co-design.

This article is grounded in the field of evidence-based design, this is its "home base" (Holweg et al 2013), and so it uses this discipline-based terminology, but then discusses the focal issue from a clinical and operations management functional perspectives. Finally, we discuss the findings by answering a single, simple question: "how does this interdisciplinary view change the findings, and is this change significant? In other words: what is the "delta" that the study identifies that we would not know about otherwise? It is this incremental or differential viewpoint that defines the value of conducting interdisciplinary research. It is the make-or-break criterion against which all those studies claiming to be interdisciplinary have to be measured" (Holweg et al. 2013).

2. Theories and Methods

2.1. Interdisciplinary Design and Innovation Research

Interdisciplinary research refers to studies that involve two or more academic disciplines working together to refine a theoretical frame to build a more complex view of the problem. Each extends and provides a new analytical alternative, and challenge, to conventional wisdom (Knights and Willmott, 1997).

Virtually all design and business challenges are multi-dimensional. In some cases, and by no means all – these problems are best addressed by combining multiple lenses (Okhuysen, 2011), to address "real-world complexity" beyond traditional academic disciplines (Holweg et al 2013). The fundamental benefits of an interdisciplinary approach are "building bridges" and exchanging viewpoints. Either "redefining" or "restructuring" parts of a discipline, or developing new "umbrellas" or "overarching concepts" that transcend boundaries (Repko, 2008). While it is not new (Ackoff, 1960; Klein, 1990; Repko, 2008), its continued application is critical in fields such as healthcare design where knowledge is fast moving and requires "boundary-spanning" to advance knowledge (Aldrich and Herker, 1977; Dollinger, 1984; Fennell and Alexander, 1987; Leifer and Delbecq, 1978).

Dynamic briefing and creative dialogues (Othman et al. 2004), agile approaches (Kollman, 2008) and physical prototyping encourages an engaged and interdisciplinary perspective. They provide a starting point to rapidly test assumptions (Ahmedab, 2019, Pianesi, 2019, Villegas et al 2019), because people may be unable to express why a design does not work (Lawson, 2001). For example, simulation and virtual mock-ups have been used for healthcare buildings (Dunston et al. 2011, Kumar et al 2011, Peavey et al 2012) to encourage reflective design (Bucciarelli, 2002, Schön, 1983), while others have used approaches such as discrete event simulation to model resource use (Brailsford et al 2001, Harper, 2002, Lehaney et al 1995, and Thorwarth 2009).

2.2. Evidence-based Design and Research-Informed Design

The integration of a whole series of issues into a solution is for some the single most important characteristic which a good designer should pursue, however it "…is often not possible to say which bit of the problem is solved by which bit of the solution. They do not map on to each other that way" (Lawson, 2006, p. 59). This contrasts with the process of evidence-based design which tries to 'scientise' design. This is a view shared by Becker and Parsons (2007) who sees the need for research to provide insights "...that can guide decisions. It does not make them". This requires "...different ways of knowing [being] filtered through the various lenses of diverse stakeholders involved in planning, designing, funding, managing, and using a facility: management, architects and planners, users, government agencies and regulatory bodies, and the community in which the facility operates" (Becker and Parsons, 2007). According to Hamilton (2004) design involves work "...informed by data from a variety of sources", and particularly from "...credible research and evaluations of projects" and "research-informed design". This requires critical thinking "...to draw rational inferences about design from information that seldom fits a unique situation precisely". The level of credibility associated with the sources of evidence range from systematic, controlled experimental studies through to single qualitative evaluations, guidance and respected authorities (Pati, 2011).

The most pioneering study was performed by Roger Ulrich (1984). This study found that surgery patients with a view of nature suffered fewer complications, used less pain medication, and were discharged sooner than those with a brick-wall view. There are now many more studies that demonstrate a causal relationship and point to predictably positive results, however there is according to Hamilton (2004) "...worry that evidence-based methods limit creativity. This overlooks the challenge of continuously inventing responses to emerging results and new facts, requiring imaginative and ever-changing interpretations of the design implications...." and could "... lead to rules and limits. "Cookbook" architecture suggests dull, repetitious buildings stamped from a mould". Research-informed design "offers complex and sometimes contradictory findings, encouraging continuous testing of new ideas".

Experience-based design has also developed alongside evidence-based design. This approach, according to Bate and Robert (2006), is close to user-focused design, which is a process that aims to make the "user experience accessible to the designers..." (p. 308), while experience-based design moves beyond a "...traditional view of the user as a passive recipient...[to] integral to the improvement and innovation process" (Gage and Kolari, 2004).

2.3. Evidence-based Design Learning Across Hospital Projects

Learning what constitutes the best design evidence across projects has been fragmented over programmes of capital investment (Phiri et al., 2011, Lindahl et al., 2010, Mills et al 2015) and so there is a significant need to facilitate the flow of knowledge (Wanigarrathna, et al 2021). This requires challenging what constitutes 'good' evidence (Green, 2000; Cairney, 2017, Lancaster et al, 2017) and the messy and complex (Oliver et al, 2014) packaging of accessible "good science" (Pullin et al 2009). Stetler (2002) and Pati (2011) for example define eight levels of evidence in relation to equivalent healthcare design studies (Criado-Perez et al. 2020).

According to Lawson (2001) and Lawson (2006) "…previous designs form one of the most important sources of knowledge…" and "Clients who repeatedly commission design expect learning to take place and designs to improve…", but this is not always the case. Learning is a critical paradigm which creates feedback loop and links within the Briefing-Design-Evaluation cycle (Lawson et al., 2001). Learning from experiences is potentially lost because projects are typically executed by temporary networks of firms that disband after the projects are completed (Akintoye et al., 2003).

2.4. Methodology

An interdisciplinary action research process was taken that engaged end-users (such as clinicians, technicians and those who address the operational challenge of environments. Table 1 details the four groups of disciplines (clinical, research, operations and outsourced services) that participated in the process across three stages. It forms the basis for a clinically-led case study. Various disciplines contributed to three unique building configurations which were devised and tested, with 1,000 patients visiting the site for a series of eye diagnostics tests under each of the three iterations of the building layout design. Circa ~ 30 staff were involved in the interdisciplinary co-design process to encourage an innovative approach to equipment configuration, layout design and an emerging scientific evidence-base.

Table 1 – Discipline-Specific Participant List (Interdisciplinary Teams included: clinical decision making, research evidence and practice-based decision makers)

Groups		Discipline	Phase 2 (Project)		
			Iteration 1	Iteration 2	Iteration 3
Clinical Leaders	1	Glaucoma Diagnostics Lead	X	X	X
	2	Medical Retina Diagnostics Lead	X	X	X
	3	Glaucoma Surgery Specialism	X	X	X
Research Evidence Teams	4	Spatial Connection Modelling			X
	5	Operations Research and Mathematics			X
	6	Prototyping / DfMA	X	X	X
	7	Healthcare Architecture			X
	8	Project / Design Management		X	X
	9	Event / Capacity Simulation		X	X
	10	Lighting Design / Engineering		X	X
	11	Connected Sensor Systems		X	X
	12	Ventilation	X	X	X
Operations and Management	13	Estates and Facilities	X	X	X
	14	Finance, Digital and Management	X	X	X
	15	HR and Personnel	X	X	X
	16	Marketing and Communications	X	X	X
	17	Technicians	X	X	X
Outsource Services	18	Equipment Supply	X	X	X
	19	Digital Systems and Sensor Networks	X	X	X
	20	General Contractor (electrical, joinery and painting)	X	X	X
	21	Architectural Layout Design and Computer Aided Design	X	X	X
	22	Project Management	X	X	X

The real-time action research (Waterman et al., 2001; Greenwood and Levin, 2007) approach applied in this study enabled a dynamic understanding of the impacts. A co-design approach was used that resulted in the prototyping of a kit-of-parts. Each iteration of the design incorporate a range of disciplines from healthcare architecture, modelling, simulation, and lighting engineering in a longitudinal case study (Yin, 1994). They would work collaboratively to develop evidence and improve the reliability of decision making. The planned unit of analysis was interdisciplinary evidence-based design, although emergent and embedded units of analysis resulted from action, observation and reflection. The principle focus of the action research was a novel consultation process to understand how evidence-based medicine, design, research-informed design and practice-based management and design might interact during project progression. Weekly project management meetings, fortnightly interdisciplinary research design meetings, a facility observation, a lighting, ventilation and spatial observational surveys of two existing buildings, a lighting and ergonomic quasi-experiment and informal interviews provided the basis of a grounded and autoethnographic account of the design process.

Engaged scholarship provided the perspectives of key stakeholders (researchers, users, clients, sponsors, and practitioners) to study the complex problem (Van de Ven, 2007) and promote innovation in collaborative inquiry and action (Gustavsen, 2005) and actionable insights (Coghlan, 2019; Lindhult, 2019). Action research was applied with little separation between analysis and action to make a direct and immediate impact on the project situation. This allowed us to recount the real-time, real-world situation observed, clarify ideas and research questions, shape and re-shape development and understand and discover, as in Orton (1997). This captured reality more effectively; however, it also introduced bias and limited the clarity of a deductive or inductive form of reasoning.

Figure 1 shows how various research teams were involved in a longitudinal case study over two and a half years. It illustrates the continued involvement of clinical teams in the clinical experiment design, it also shows the various teams providing evidence to inform a practical process of design, manufacture and install. The research informed-design was focused on two evaluations of existing buildings and the iterative design and re-design of a ophthalmology diagnostic hub for low intensity repeat/follow up patients.

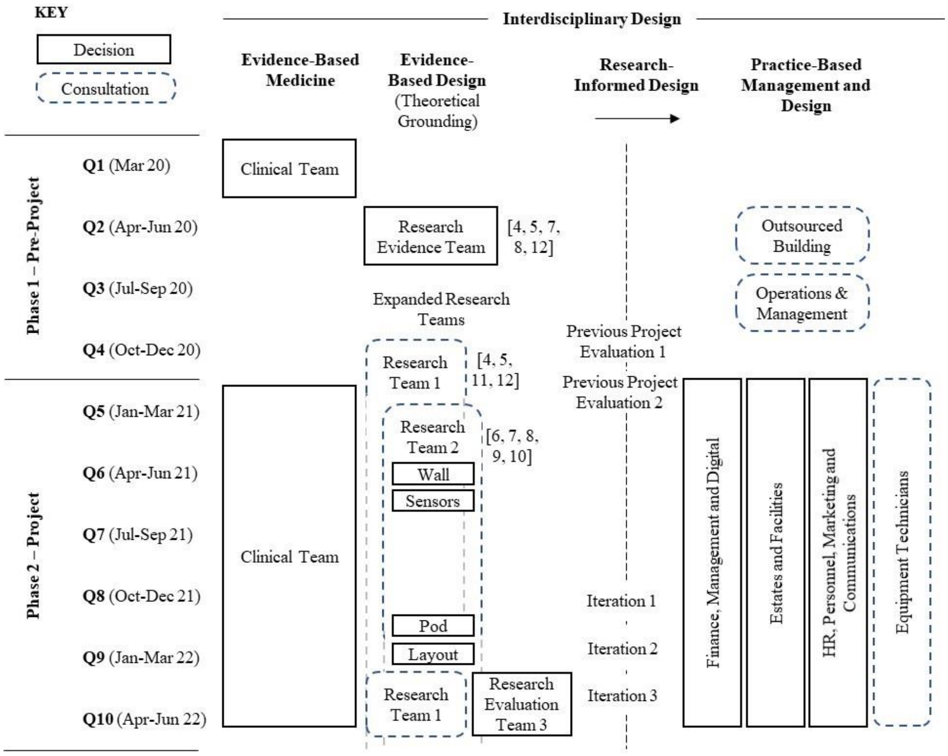

Figure 1 – Record of the Progressive Involvement of the Interdisciplinary Design Groups Incorporating Evidence, Research Informed Design and Practice-based Management and Design.

By way of an examples of the disciplines involved in the action-research, the following represent specific tasks that influenced action:

- Prototyping / DfMA (6) – Developed flexible grid layouts and prototypes for a reconfigurable, movable, low carbon, waste minimizing and low cost walling system. Surveyed the ergonomics and choreography of the equipment layout. Designed and manufacture two pods for different layout and equipment configurations.
- Healthcare Architecture and Event/Capacity Simulation (7 and 9) – Rapid review of literature and national standards. Surveyed clinical and technician staff on the clinical processes, layout preferences and equipment use. Ergonomic drawings for the pods and spatial layout drawings for iteration 3.
- Lighting Design / Engineering (10) – Undertook a lighting survey and anecdotal interviews of two previous projects, investigating the lighting requirements for different equipment, and provided expertise in the design of two environment-specific equipment pods.

3. Results

This section describes the interdisciplinary process of designing a virtual diagnostic hub for eyes. Figure 2 shows the potential elements and kit-of-parts that interacted across the various stages of the interdisciplinary eye hubs design. Numbers i-vii represent the various design principles that drove the design, while a-f represent the prototype product and process features (termed the kit of parts) that were changed throughout three stages of iteration 1-3.

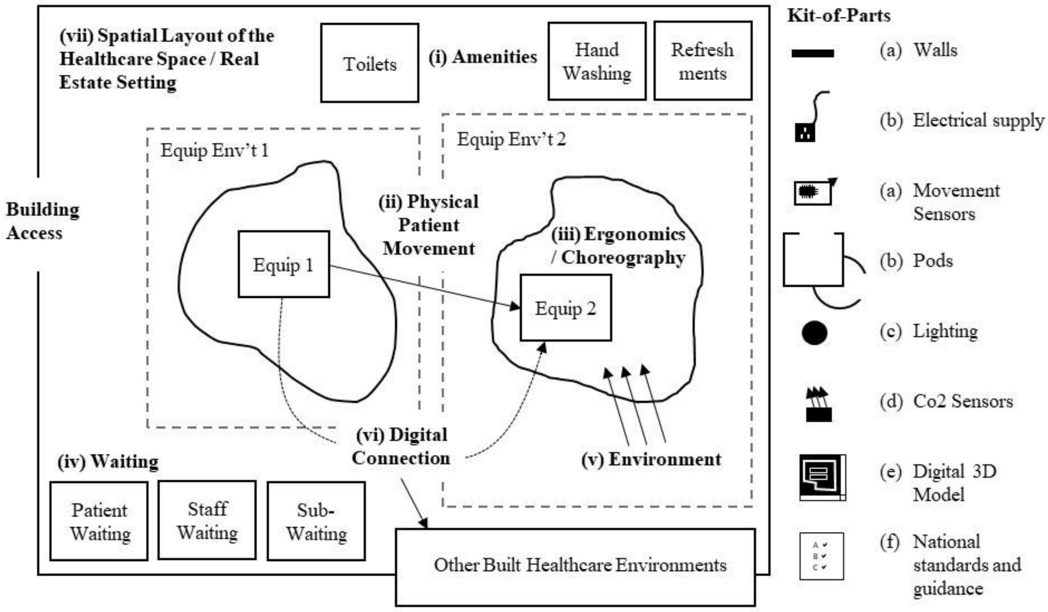

Figure 2 – Interconnection of the Various Elements of the Virtual Diagnostic Hub

We now describe how various interdisciplinary design principles drove a new kit-of-parts that enabled a more integrative research-informed design process.

- Spatial Layout (vii) – The interdisciplinary influence on the layout was significant in iteration 3 (All discipline groups influenced the layout (clinical team – disciplines 1-3, research evidence teams – disciplines 4-6, and operations and management and outsourced services – disciplines 13-21). In addition, the final layout incorporated detailed evidence on decisions associated with amenities (i), physical patient movement (ii), equipment ergonomics (iii), waiting (iv), environment (v), and digital connection (vi). The digital connection (vi) between equipment, and specific data flows between machines, drove new layout sequencing needs.
- Walls and Electrical Supply Parts (a and b) – Interdisciplinary connections to influence the wall and electrical supply were principally across the clinical team (disciplines 1 and 2), research evidence teams (disciplines 6, 7), operations and management (13) and outsources service providers (disciplines 20 and 21). Many of the decisions associated with the wall and electric design were made on the basis of procurement deadlines, practicalities and preferences. Some defective components emerged, some user expressed disbenefits (e.g. privacy and acoustics) and principles such as wall flexibility forgone for speed.
- Movement and CO2 sensor parts (c and f) – Interdisciplinary engagement in the specification and design included clinical teams (disciplines 1 and 2), the research team (disciplines 9 and 11), operations and management (disciplines 13, 14, 7 and 19). There were significant opportunities for interdisciplinary data integration and vali-

dation and various spatial layout reconfigurations impacted data quality. For example multi-equipment lanes were less accurate than single equipment pools or pods as there was less granular data on equipment use or in lane sub-waits.

- Pods and Lighting (d-e) – Interdisciplinary integration across clinical (1), research evidence (6, 7, 8, 9, 10, 11, 12) and operations and management (13) to allow a new pod design. A mock-up and anecdotal survey showed the range of machine specific functions required of task lighting, as well as the limitations and opportunities provided by spill light. The configuration of one piece of equipment (Humphrey Field Analyzer) was significantly influence by lighting changes and its use required lower lighting levels compared to other machines. The wider environment of the centre was designed for low lighting, although the manufactured pod created increased lighting flexibility for both patients and staff.
- Digital 3D model (g) – The digital 3D model had a significant influence on the design and installation of the various parts. There was accessibility, redrawing and compatibility challenges that influenced the integration of interdisciplinary contributions.
- National Standards and Guidance (h) – There was disciplinary guidance produced by the CIBSE Society of Light and Lighting, the Royal College of Ophthalmologists guidance notes for lighting of optometric practices, Health Building Notes (HBN) and Activity Data Base (ADB) room data sheets. We were able to show opportunities for development, bringing up-to-date and alignment of technical requirements.

The design for iterations 1, 2 and 3 changed. Iteration 1 had a looped design with four pathway activities separated for Medical Retina (MR) and Glaucoma (GL). Iteration 2 had equipment pools that fully amalgamated patient pathways into ether five or six pathway steps. Iteration 3 (Figure 3) had a five activity hybrid design with dedicated and shared clusters and pods. Iteration 3 achieved a consistent step-together flow for both pathways.

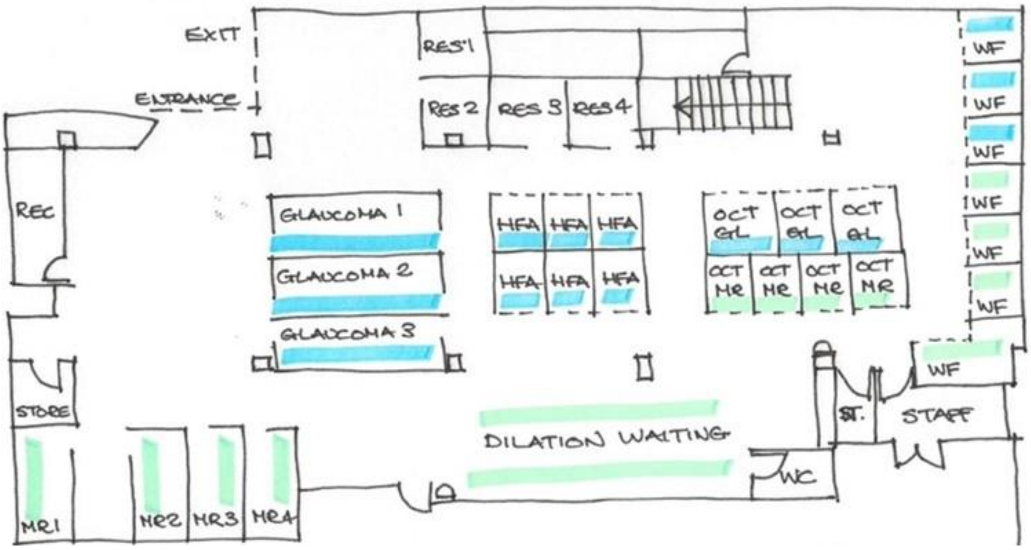

Figure 3 – Iteration 3 Virtual Diagnostic Hub Spatial Layout Design

Separating patient pathway circulation and staggering the arrival of patients by 10 minutes reduced patient contact and created a swift and even flow. Iteration 3 was judged to be the most successful and was delivered through an interdisciplinary approach. Early eye history (as preferred by the techs), timing matching across Glaucoma and Medical Retina (e.g. HFA[1] and Dilation waiting coincide) and beneficial equipment banks/pools and equipment-customized lighting resulted. It also created clear/open circulation routes

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[1] Humphrey Field Analyser (HFA) a tool for measuring the human visual field that is commonly used by optometrists, orthoptists and ophthalmologists to detect the progression of vision loss and the patient's condition.

(as preferred by techs/patients) and improved patient wayfinding/tech sightlines and utilized pooled/banked equipment (to improve flow).

4. Discussion

We return to the question - how did this interdisciplinary research change what we know, and was it significant? The results of the research certainly provided a variety of evidence sources, and a number of theoretical and analytical alternatives to review the design. An umbrella concept that emerged for all disciplines was the need for iterative dialogues that created an adaptive and creative co-design process. This started with a clinically-informed and technology-driven process that iterated between evidence and practice. This process of informing design was reflexive and adaptive (uses dialogue) to translate evidence into action (Lancaster et al 2020). It bridged various forms of evidence and expertise throughout each iteration building credibility around a design and then informed the development of a prototype. The principle of evidence-based medicine, evidence-based design and evidence-informed design were simultaneously observed, but so was an un-informed design (from both evidence and practice). Lessons associated with the use of non-infection control compliant pod curtains, toilet and refreshment requirements, wall height and mechanical filtration acoustic and task lighting that were evidenced to inform future designs.

Interdisciplinary research played a key role. For example we exchanged viewpoints between design and engineering and clinical and technical practitioner disciplines, when considering patient flows and clinic efficiency. The clinical team were able to understand the variation caused by facilities planning and patient amenities. Conversely, modelling and spatial layout experts restructured their thinking to consider technological, clinical, patient and staff factors, beyond for example walking distances, adjacencies and sight lines. The work has raised many more questions associated with air movement and cross-infection, patient access and connecting multiple-site environments. What it has most significantly shown is the need for future interdisciplinary iterative dialogues to integrate lessons both locally and nationally (Mills et al 2015). This clinically-led and integrative approach will be the antidote that overcomes the methodological challenges of a heterogeneous evidence-base in building design. One that facilitates higher quality decision-making and raises the credibility of decisions (Evans, 2003; Hamilton, 2003; Stichler, 2010, Benbya and McKelvey 2006).

5. Conclusions

The problem has always been that there are many fields, numerous types of evidence and different disciplinary ways of designing healthcare infrastructure reconfiguration. An iterative evidence-seeking design process is demonstrated that encouraged interdisciplinary views to be shared. We challenge eyecare diagnostics reconfiguration and offer up a conceptualization of an ongoing evidence-based co-production process. Specifically, we document the response to an urgent need to improve access and reduce waiting times for specific patient specialties. In this case, we repurposed an empty retail unit into an innovative diagnostics hub for two eye diseases (Glaucoma and Medical Retina) to reduce patient backlog from nineteen weeks to two weeks in some areas of the hospital catchment. Our hope is to create more agile structures for knowledge sharing during design, to work with clinical leaders and as part of interdisciplinary teams to correct the uninformed design that will inhibit effective healthcare infrastructure reconfiguration.

Contributor statement

PF, GM, SS, JJ conceived the research design. AS, IR, JUT, PS, KS, DW, PF, GM, HJ, SS were involved in the action-based design process. GM provided the literature, data interpretation and first draft of the manuscript, with comments from PF, AS, IR, JUT and DW. All authors read and approved the final manuscript.

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