IAD 662 DISSERTATION

Can spatial arrangement influence the facilitation of cross disciplinary collaboration within laboratories?

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Figure 1: Cover Illustration

Abstract

Living Laboratories are fundamentally underpinned by cross contact between disciplines to foster collaboration, leading to innovation. Functioning in real life contexts, with active user involvement, these interactions form open innovation ecosystems. Although widely recognised as a key component in the design of laboratories, little research has been carried out to establish the importance of spatial arrangement in facilitating cross disciplinary collaboration. The aim of this study is to establish to what extent adjacency and spatial arrangement influence the productivity of laboratories in regard to co-production. This research will be conducted by reviewing case studies of three prominent laboratories. Analysing their spatial arrangement with regard to its influence on collaboration through consciously encouraged and subconsciously influenced connections. The study will focus on evaluating three aspects. Firstly, the adjacency of programmatic requirements. Secondly, the flow of circulation spaces and journey routes. Lastly, the ancillary spaces, the informal non-specific spaces that complement the formalised facility spaces. The study presents a qualitative analysis of each aspect measured against the perceived benefit to cross disciplinary collaboration. The findings of this study suggest that the spatial organisation of a laboratory can be designed to influence the facilitation of positive cross disciplinary collaboration. Consequently increasing productive output, when combined with adaptable, fit for purpose facilities.

Understanding spatial representation and facilitation of interdependent connections will enable me to design my Final Portfolio Project to promote the primary aim of a Living Laboratory, collaboration.

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Introduction

Attitudes towards health and well-being are shifting. The World Health Organisation defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." (WHO, 2022). The approach of health as a holistic whole is not new. Pioneers of science such as Jonas Salk emphasised the need for "the study of both the body and mind of the 'total person'". (Steele, 1999). This perspective is being pushed to the forefront of agendas, accelerated by the Covid-19 pandemic, opening a new dialogue as to what the future landscape of healthcare will look like. One answer could be Living Laboratories.

Living Laboratories are real-life research environments that directly engage end users, through participation. Fundamentally underpinned by cross disciplinary collaboration, Living Laboratories aim to foster co-production. Co-production tends to define the relationship between citizens and service providers, enabling end user participation in the design process. Nesti (2015) defines "full co-production" as "entail[ing] users and professionals totally sharing the task of planning, designing and delivering the service." (Nesti, 2015, p.3). The theorised benefit of this process is an improvement of outputs. Moreover, "greater public involvement in research and innovation can serve to legitimize research trajectories and produce more welcome, sustainable innovations". (Schutz, Heidingsfelder, and Schraudner, 2019). In this context a Living Laboratory is the physical space facilitating collaborative co-creation.

A key proponent in the advancement of new scientific discoveries is cross disciplinary collaboration. Although the importance of collaboration within laboratory environments is recognised, little research has been carried out to establish the influence of spatial arrangement on interaction between occupants. Principally, if these interactions lead to positive, productive collaborative outcomes. This study aims to fill this gap by presenting the results of a qualitative analysis comparing case studies of three prominent research centres. The paper proceeds in three main parts, each chapter presenting a different case study, analysing their spatial arrangement with regard to its influence on collaboration through consciously encouraged and subconsciously influenced connections. The Salk Institute for Biological Studies, the Schlumberger Cambridge Research Centre, and the Sainsbury Wellcome Centre have each been chosen due to their pioneering designs (at the time of their construction). Each will be analysed considering the following:

1) the adjacency of programmatic requirements
2) the flow of circulation spaces and journey routes
3) the ancillary spaces, the informal non-specific spaces that complement the formalised facility spaces

to establish if the design and manipulation of these elements can be beneficial to cross disciplinary collaboration. The findings of this study can suggest if the spatial organisation of a laboratory can be designed to influence the facilitation of interdependent connections. Subsequently increasing productive output, when combined with adaptable, fit for purpose facilities. When evaluated and applied specifically to the model of the Living Laboratory an understanding can be formed of the future design direction of laboratories. When applied to the Final Portfolio Project the primary aim of a Living Laboratory, collaboration, can be promoted as a means of improving healthcare services.

Literature Review

The focus of this study is to investigate the role and influence of spatial arrangement, within laboratory interiors, on the facilitation of cross disciplinary collaboration within Living Laboratories. As recognised by Nesti (2015, p.2) while "the literature on LL [Living Lab] methodology has grown impressively, empirical research of its strengths and weaknesses is still scarce" and further investigation needs to be made into the aspects that enable their failure or success. Many recent studies have focused on the components of Living Laboratories, and those elements required for their success in facilitating co-creation across disciplines; but have not looked to evaluate and review in depth the influence of spatial arrangement on aiding the achievement of the principle goals of a Living Laboratory.

Primarily the principles and goals of a Living Laboratory, as identified by the European Network of Living Labs (ENOLL) (2022) are: empowering knowledge exchange; working across disciplines; having no end date - following a lifecycle approach; using real conditions and environments; being inclusive and adaptable. The concept was first proposed by Professor William J. Mitchell of MIT Media Lab as "a research methodology for sensing, prototyping, validating and refining complex solutions in multiple and evolving real-life contexts." (FISSAC, 2022), to find "solutions for challenges related to health, energy and creativity". (Nesti, 2015, p.5).

Throughout the literature there is consistent evidence that the two key aspects at the forefront of consideration when designing a laboratory are firstly future adaptability; as science and technology rapidly innovates, with future demands unpredictable at the time of building. Secondly, encouraging and fostering collaboration between different research groups and between individual academics.

When reviewing the literature surrounding the three case studies a common prevailing approach emerged. Each architect (Khan, Hopkins, Ritchie) looked first to existing laboratories before embarking on their own design. This highlights the importance of understanding the practical and service demands of a laboratory space to enable a successful design. Arguments have been made that the design of a laboratory is simply to act as a background for the science taking place, simplified to a "set of rooms and facilities". (Lynch, 1985, cited in Yaneva, 2022). This simplistic perspective highlights the minimum requirement for a research centre, to be fit for purpose. To strive beyond this creates the opportunity to expand the capability of the built environment; into a positive working atmosphere, conducive to facilitating cross disciplinary collaboration. The process of striving beyond this has been documented in depth by Ferry (2017) expanding upon the research process undertaken by Ian Ritchie Architects (now Ritchie Studio) before designing the Sainsbury Wellcome Centre. "We emphasised … it was impossible to design a building until we knew ... the current and emerging techniques in use …, their use of space, and the behavioural patterns of neuroscientists and their support staff." (Ritchie in Ferry, 2017, p.47). Whilst a recognition must be made that the text's key contributors are those who are key stakeholders, with active interest in the building being perceived a success, the literature provides an in depth look at the process of the buildings design from initial conception through to completion. This rare insight of candour from all parties, including architect, client, engineer and end user, is arguably a key source, that cannot be overlooked.

Over the recent decades the attitude towards collaboration within the scientific community has gradually shifted. Where typically different research groups and sectors would remain separated in different silos, focusing on their individual research projects, a shift in attitude has recognised the importance of cross collaboration to enhance possible outputs. This encourages conversations to introduce new perspectives and combine methodologies. One such example is the exchange between computational neuroscientists and experimental neuroscientists as cited by David Sainsbury in Neural Architects (Ferry, 2017), posing the hypothetical of a computational neuroscientist opening the dialogue to an experimental neuroscientist that "theoretically this is how you can do this, but do you have any experimental evidence?" (Sainsbury in Ferry, 2017, p.158), and vice versa. This connect or disconnect between individuals can be directly reinforced by the spatial layout and division of a space. "The internal representation of a place is strongly influenced by the way in which an individual moves within it, with different places connected based upon the ability to move between them." (Sternberg and Wilson, 2006). If principle investigators and post-docs all become separated in cellular offices, a psychological barrier is created, preventing conversations. This in turn becomes a damaging barrier to research progress. Equally different research groups need a visual connection or movement cue to encourage them out of their separated areas and into shared spaces where encounters with other groups can take place. As identified by Sternberg and Wilson (2006) if an individual cannot move directly from one location to another "the hippocampus will treat them as separate places". (Sternberg and Wilson, 2006).

Although the importance of encouraging cross disciplinary collaboration is widely recognised as a key component in the design of laboratories, (as a key proponent in the advancement of new scientific discoveries), little research has been carried out to establish the impact of spatial arrangement on interaction, both consciously encouraged and subconsciously influenced, between individuals. Principally, if these interactions lead to positive, productive collaborative outcomes.

Establishing if these interactions lead to positive, productive collaborative outcomes can help to support the promotion of the Living Laboratory model by governments and the European Union. As "governments are prioritizing greater public involvement in innovation processes" (Schutz, Heidingsfelder, and Schraudner, 2019) and the Living Laboratory model answers to this. "The former European Commission strongly encouraged the adoption of LLs [Living Labs] as a means to improve EU competitiveness and growth." (Nesti, 2015, p.6). The use of the title 'Living Lab' has been adapted by research centres across the world, helping to attract investment. By understanding the impact the design of the space accommodating the research has, better recommendation can be made to inform new emerging projects.

The European Network of Living Labs (2022) recognises that the interaction of Quadruple Helix Model (academia, society, government, industry), originally conceptualised by Elias Carayannis and David Campbell (Schutz, Heidingsfelder, and Schraudner, 2019), is the key to fostering co-creation and innovation within Living Laboratories. As identified by Schutz, Heidingsfelder, and Schraudner (2019) the relationship between the four stands of the Quadruple Helix of innovation is non-linear. This non-linear basis of interaction requires a re-evaluation of the best way to foster collaboration within interior spaces to enhance the production of knowledge. The development of the so-called 'hybrid lab' (Yaneva, 2022) in response to the demands of research environments that require "a specific social and cultural organization, involving a range of shared spaces for material scientists, engineers, chemists, physicists and people from industry" (Yaneva, 2022) appears to pave the way for a new blueprint. However, notions around creating a research environment that is not exclusive to one distinct scientific strand have existed long before. In 1959 when conceiving of the idea of a new research institute Jonas Salk promoted the idea of "a new attitude towards biological research, in which the humanities were not only seen to have a part, but in which physics and chemistry, traditionally seen as distinctly different studies, were now considered to be merged." (Weaver, 1963, cited in Steele, 1999). "Salk was convinced of the importance of this crossdisciplinary understanding", (Sternberg and Wilson, 2006) choosing to include in the faculty scholars of mathematics and humanities.

This study aims to review and analyse case studies of existing laboratories and research centres, spanning the past six decades. By comparing these case studies and their individual approaches to spatial arrangement, via qualitative examination, conclusions can be drawn with regard to the extent of success in increasing contact between parties. When reviewed and applied specifically to the model of the Living Laboratory, an understanding can be formed of the future design direction of laboratories.

Figure 2:
Salk Institute Courtyard with view towards the Pacific Ocean.

1. Salk Institute for Biological Studies, Louis Khan (1959-1965)

The Salk Institute for Biological Science in La Jolla, California (Figure 2) is the second laboratory designed by Louis Khan, the first being the Richards Medical Research Building at the University of Pennsylvania. At the Richards Medical Research Building Khan expressed the plan as a "combination of the linear and the particulate" (Curtis, 1996, p.519), "enabling its occupants to look across into each other's laboratories." (Weston, 2004, p.128). This visual connection was enabled in part by the distinct separation of "the serving and the served" (Curtis, 1996, p.519), an expression of Khan's pursuit for order that saw the separation of the laboratories from the services as cellular elements. Post completion the Richards Medical Research Building showed itself to be flawed, with a "lack of functional flexibility". (Curtis, 1996, p.520). Nevertheless the key lessons learnt here regarding future adaptability could be applied to the Salk Institute, arguably becoming one of the greatest attributes to the design of the Salk Institute. The organisation and clear, logical system of servicing and structure in the Richards Medical Research Building (Curtis, 1996) can be seen articulated to a higher level at the Salk Institute.

The prior experience and architectural philosophy of Khan combined with the ethos and vision of Jonas Salk created a new paradigm for laboratory design. "The Salk [Institute] was the starting point for using the building to support the scientific community rather than just provide space." (McGhee, n.d., cited in Bonetta, 2003). The centre was intended to "promote an holistic approach to health in which the humanities, as well as the 'hard' sciences" (Weston, 2004, p.138) live in harmony, working side by side. This approach created a demand for a space that would reflect "the place science should occupy in modern culture" with "a new attitude towards biological research". (Weaver, 1963, cited in Steele, 1999).

The expression of this new attitude is visualised in the built form as two linear, non-hierarchal, ground hugging blocks. (Figure 3) The symmetry of the design, joined by a shared courtyard, (Figure 2) answered to Salk's concerns that people working in separated buildings, with separated courtyards, could lead to a possibility of competitiveness between individuals working in buildings with opposing facilities. (Steele, 1999). Here the programmatic requirement sees not only the functionality answered to, but the inherent underlying philosophic principles. The emphasis on non-hierarchy is conducive to a collaborative attitude.

Another expression in response to the philosophy of the institute is reference to "forms of intellectual retreat" (Curtis, 1996, p.522), such as monasteries. Salk's high regard for the monastery of St Francis of Assisi reflects as a strong influence on the design of the Institute. The principles of retreat explored in the materiality, landscaping, and setting, create a calming background complimentary to the active, formalised work spaces. The importance of reflective space has been shown to create a positive working environment (Boud, Cressey, and Docherty, 2006), conducive to productivity, due to higher morale in occupants. The more prominent likeness to monastic design is expressed in the arrangement of the arcade of 'cloisters' directly off the central courtyard. Serving as a transition point the 'cloisters' align directly to the studies above, referred to as 'porticoes of studies' in Khan's drawings. (Steele, 1999; Weston, 2004). The studies are linked by bridges to the laboratory spaces, (Figure 4) or perhaps more accurately separated from the laboratories by bridges; "in order to maintain a sufficient physical and psychological distance between the two." (Steele, 1999). This distinction marks the difference between the spaces "of shared endeavour and the private world of thought" (Curtis, 1996, p.522), with an emphasis placed on the studies as a space for contemplation. The angular design means every study has a view of the Pacific Ocean, again emphasising the non-hierarchal attitude. (Figure 5)

In contrast to the cellular 'porticoes of studies' the laboratory spaces comprise of vast open plan expanses. (Figure 6) The uninterrupted floor plate, with no internal structure, allows for ultimate adaptability for the research teams occupying the space, to choose how they want to divide and use the space. Thus empowering the researchers with ownership over the space. The openness and adaptability of the laboratory space is supported by the interstitial space for mechanical services that occupies a whole floor above each laboratory. This integrated functionality has allowed the building the flexibility to evolve over time. (Curtis, 1996; Ferry, 2017; Moe; 2008; Steele, 1999; Weston; 2004). The prioritisation of uninterrupted research, as identified by Moe's (2008) in situ extended observation, is married by possibility for simultaneous uninterrupted maintenance work (Moe, 2008, p.19). Consequently the researchers occupying the laboratory can function at their highest possible rate.

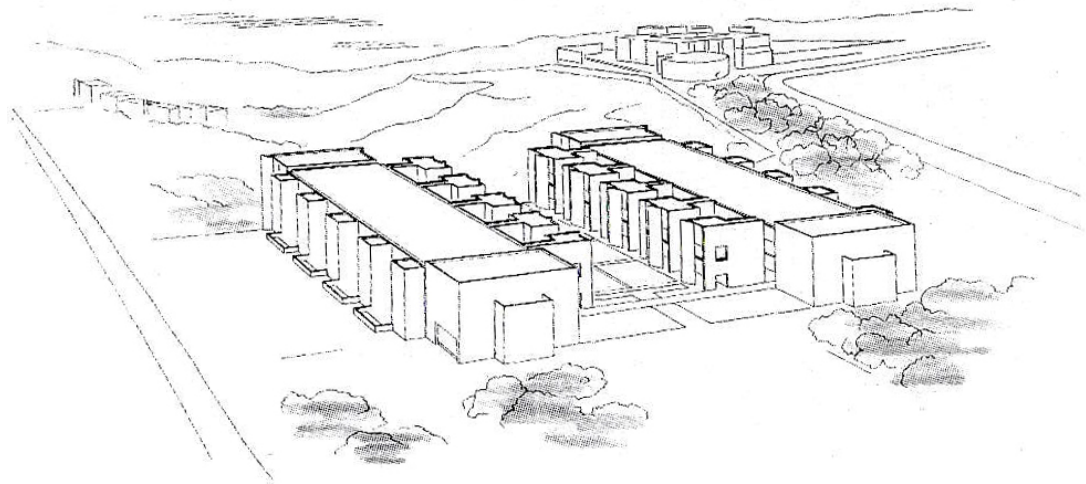


Figure 3: Linear ground hugging blocks.

Figure 4: Connections to the 'porticoes of study' via bridges and stairs.

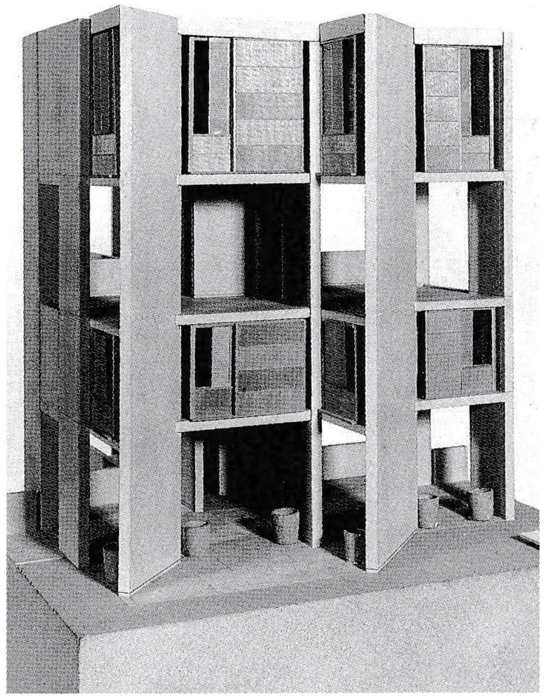


Figure 5: Model of the Salk Institute, featuring the 'porticoes of study'.

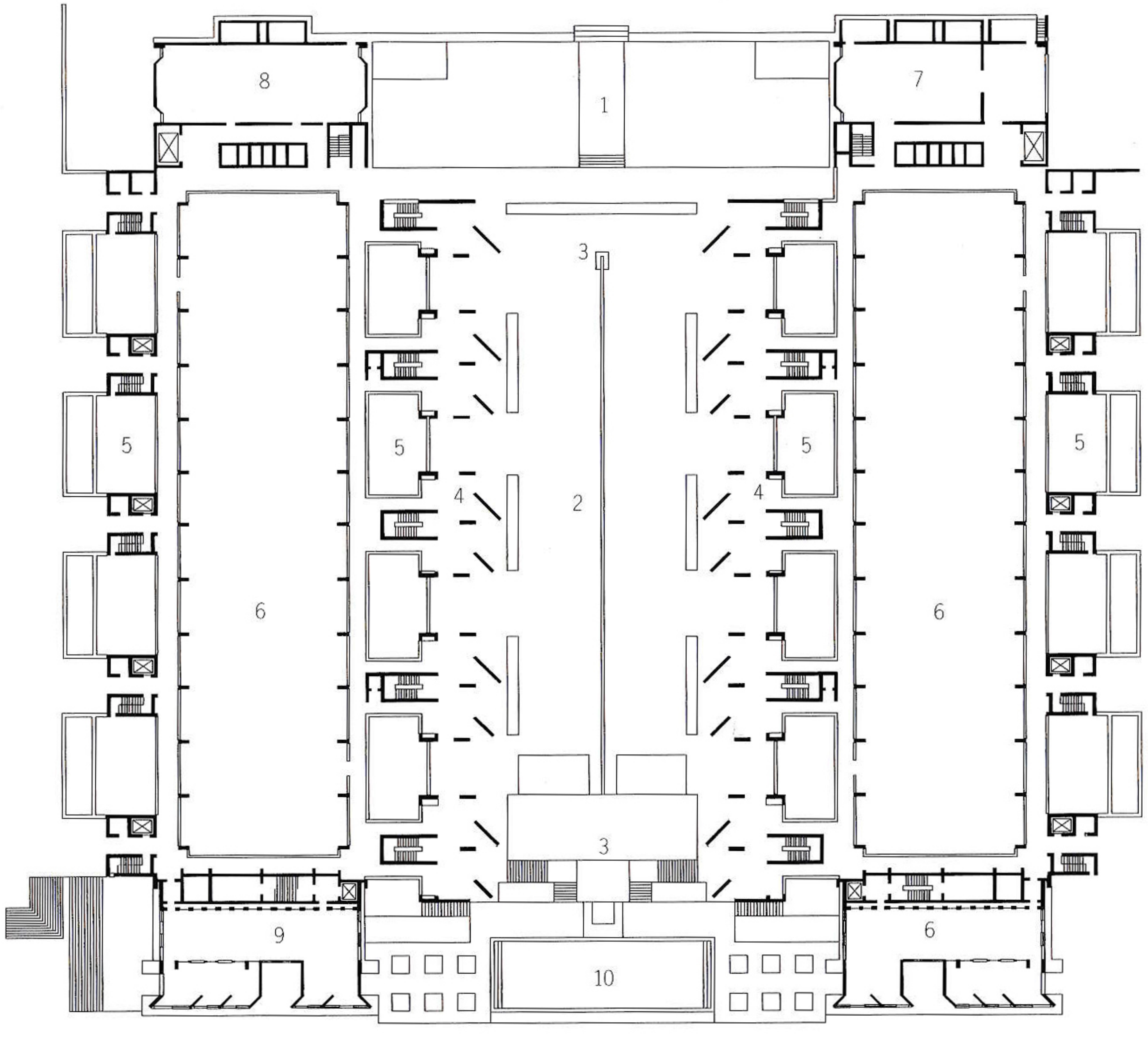
Figure 6: Open laboratory floors in the Salk Institute.

Figure 7:
Circulation spaces at the Salk Institute.

All connections between separate functional spaces (i.e. laboratory, study, library) are external. (Figure 7) This is appropriate to the climate, but more importantly it creates the opportunity for subconsciously influenced connections. The width of the outdoor circulation corridors combined with strategically placed slate panels (Ferry, 2017, p.55) and furniture, transform the circulation route into an informal, non-specific space where interaction is facilitated. The slate panels serve as instant blackboards, and now too the glass facades become whiteboards, to support the interactions between researchers. (Ferry, 2017, p.55).

If the circulation spaces mark the beginning of the ancillary spaces then the complimentary component is missing. The unbuilt Meeting Place appears to supply the answer to total cross disciplinary collaboration. Designed to contain lecture halls, an auditorium, enclosed courts and an ambulatory (once again reflecting monastic design typologies), it would reinforce the message of equality between researchers from different ranks and backgrounds; further encouraging co-production. The space would foster the community that now arguably suffers from a lack of communal space. Lastly, it would have accommodated the philosophical aspect, presented by academics, that cannot be expressed in a laboratory. (Steele, 1999). Steele (1999) proposes that "if the laboratories may be referred to as the lungs of the Salk Institute, the Meeting Place was to be its brain, and the body is incomplete."

Many regard the unbuilt Meeting Place as a great loss due to its place in Khan's architectural evolution (Steele, 1999; Weston, 2004), conversely its loss is greatly felt from the perspective of supporting a new scientific community that sought to combine all three disciplines of science, alongside humanities. The merit of the Salk Institute can be garnered from the subtle support of consciously encouraged and subconsciously influenced connections it provides. The quality of the working environment; providing truly adaptable laboratories coupled with close proximity, yet psychologically detached, studies; enables optimal performance by the occupiers. As the users are encouraged to take ownership over the space impromptu collaborations are supported, most prominently demonstrated in the circulation spaces, facilitated via informal vertical writing surfaces. All underpinned by Salk's original vision that remains prominent in literature.



Ground Floor Plan at Laboratory Level

1 Entry from Torrey Pines Road
2 Central Court
3 Fountain
4 Portico of Studies
5 Light Well
6 Laboratory
7 Mechanical Services
8 Photo Laboratory
9 Library
10 Terrace

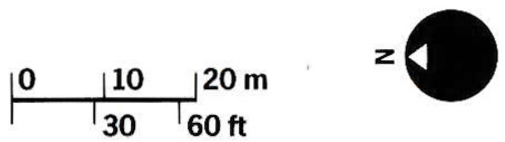


Figure 8:
Salk Institute ground floor plan.

2. Schlumberger Cambridge Research Centre, Michael Hopkins (1985-1992)

In 1982 Michael Hopkins and Partners were appointed to design the new Schlumberger Research Centre, in Cambridge, England, to accommodate Schlumberger's multi-disciplinary team of scientists. The result is a building that sits at contrast to its surrounding landscape, in a "meadow replete with sheep. This setting only enhances the building's otherworldliness." (Ellis-Miller, 2016 in Buxton, 2016, p.37). (Figure 9) Answering to the most prominent functional requirement of any research centre, future adaptability, the building is "deliberately open-ended, allowing the possibility of modular expansion in either direction." (Jenkins, 1993).

Figure 9:
The Schlumberger Cambridge Research Centre at night.

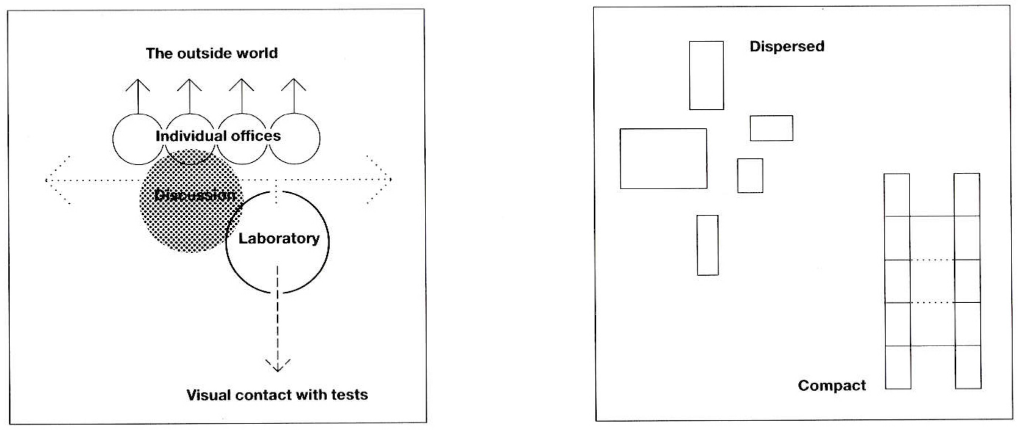


Figure 10:
Diagrammatic exploration of the interdepartmental relationships and arrangement of elements of the Schlumberger Cambridge Research Centre.

From the beginning the design brief supported the facilitation of cross disciplinary collaboration. Schlumberger "articulated a requirement for the maximum physical and visual cross-contact between the centre's constituent departments". (Jenkins, 1993). This not only regarded those working daily in the building, but also encompassed facilitating cross contact between those visiting the building, namely university scientists, or staff from other companies. (Jenkins, 1993). The arrangement of the building is dictated by a 'form follows function' approach, with interdepartmental relationships expressed in the spatial adjacency of the plan. (Figure 10) Each separate element of the plan has an assigned spatial condition, defining the function. They are prescribed as follows: individual private study rooms are outward facing; laboratories are inward facing; test spaces (the test station defines the purpose of the centre) are central; social gathering space is central; impromptu meetings and connections are in open discussion areas and circulation spaces. (Jenkins, 1993). The adjacency of spaces combined with the transparency between spaces encourages interaction between occupants.

The narrative of the building can be read throughout the building due to the transparency between spaces and the relative adjacency of the spaces. This perceived openness fosters social integration between parties as barriers to communication are broken down. In turn this supports cross disciplinary interaction. Consciously encouraged and subconsciously influenced connections are supported by the circulation spaces that form a key dimension in the plan of the building. The plan of the centre "encourage[s] lateral movement across the building" (Ellis-Miller, 2016 in Buxton, 2016, p.37), creating the opportunity for casual meetings. These meetings are in turn facilitated by the width of the circulation routes, that are widened further at "strategic crossing points". (Jenkins, 1993). (Figure 11)

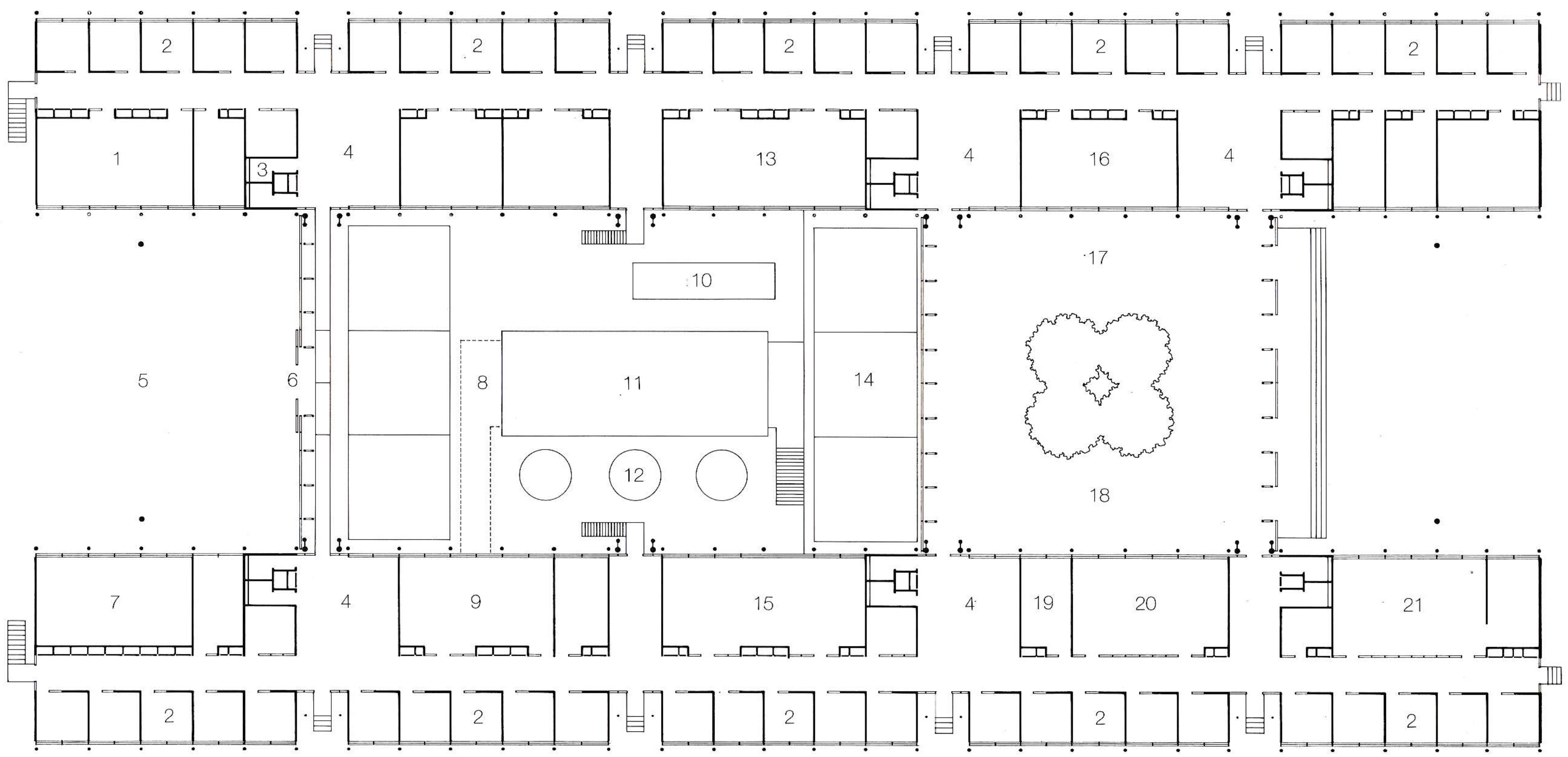
The most prominent case of transparency is exhibited in the winter garden. (Figure 12) This ancillary space that compliments the formalised functional work spaces served as the original entry point (before the 1992 linear extension). From here the experimental test station, the focal point of the centre, is on full display. Beyond this the inward facing laboratories and service area can be seen. Once again reinforcing the visual cross contact between all parties who enter the building. A growing aspect of laboratory design, and indeed all workspaces, is the informal, non-research spaces "whose area ratio has grown considerably since the 1990s." (Klonk, 2016, cited in Yaneva, 2022). These informalised spaces of gathering provide an alternative form of connection to the impromptu meetings in circulation routes. The environment is conducive to longer conversations, in particular to conversations that fall outside of research topics. This in turn establishes personal connections that can be drawn on later in a research specific context. Equally of note the provision of social space contributes to a positive working environment. Furthermore, "depriving the occupants of daylight and the ability to stay visually oriented has negative consequences on their performance and mental well-being". (Goldstein, 2006). In the winter garden and throughout the Schlumberger Research Centre access to natural daylight is constant. Occupants with a higher morale and positive working atmosphere are more likely to be open to collaborative opportunities.

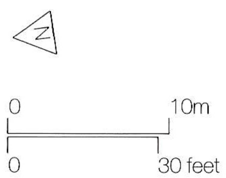
The success of the building can perhaps be measured in its continued use to present day. Of greater precedence is the spatial arrangement that is legible to all inhabiting the space, instantly breaking down barriers between occupants. Likewise this legibility is advantageous to collaboration with visitors of the building. The spatial arrangement combined with the journey spaces is masterfully managed to influence connections both consciously and subconsciously. This is accomplished through a balance between physical and visual cross contact.

Figure 11:
Widening of circulation space to accommodate informal meetings.

Figure 12:
Winter Garden in the Schlumberger Cambridge Research Centre.

1 rock physics laboratory
2 scientist's room
3 wcs
4 discussion area
5 service yard
6 bridge in front of service entrance
7 double-height workshop
8 access tunnel
9 drilling mechanics laboratory
10 flow loop pit
11 underground high-pressure pump chamber
12 drilling pits
13 fluid mechanics laboratory
14 drilling test station
15 wellbore physics laboratory
16 kitchen
17 restaurant
18 winter garden
19 archive
20 library
21 laboratory
22 seismic laboratory
23 plant
24 meeting room
25 entrance hall
26 rheology laboratory
27 main entrance and terrace
28 conference room
29 teaching wall
30 bridge above entrance hall
31 computer room





Test station building, ground floor plan

Figure 13:
Schlumberger Cambridge Research Centre ground floor plan.

Figure 14:
Artist render of the Sainsbury Wellcome Centre facade.

3. Sainsbury Wellcome Centre, Ian Ritchie (2009-2016)

Like both the Salk Institute for Biological Science and the Schlumberger Cambridge Research Centre the facilitation of cross disciplinary contact in the design of the Sainsbury Wellcome Centre (in London) was driven directly by the project's advocate. David Sainsbury said "Our aim was to provide the scientists with a pleasant working environment, and maximum flexibility", and more notably "the layout of the building should also encourage frequent encounters between scientists and a collaborative ethos within the laboratory." (Sainsbury in Ferry, 2017, p.6).

When approaching the design of the new laboratory Ritchie came with an empty proposal, instead spending several months devoted to researching and understanding laboratory design. This was achieved through a mixture of visits to existing laboratories (including the Salk Institute) and engaging with scientists through workshops and informal conversations about what they wanted from the new space. The outcome of this is a design that not only succeeds from a functional perspective but also answers to the specific nuances of the community working in the building.

Located in a dense urban site in central London the low linear plan adopted by Khan and Hopkins would not work here. A unique solution to optimising interaction between researchers was proposed to create vertical connectivity and break the main barrier within the building, the floors. (Ferry, 2017, p.89). (Figure 15) Within the building are four laboratory areas, each designed as a two storey space. Envisioned that all laboratory spaces would be shared, this accommodated the option of separate teams each having their own two storey area if the need arose. The upper floor of each wraps around a double height space, crossed by bridges, and connected to the lower level by an open staircase. (Ferry, 2017, p.90). (Figure 16, 17) The upper floor is designed as a write up space, physically separating it from the laboratory space, yet remaining visually connected via the atrium. Moreover this facilitates connection between individuals working at different seniorities within the laboratory. This visual connection breaks individuals out of closed cells and provides an awareness of other activity in the space. Lastly the two storey configuration prevents the effects of hierarchy that would be present if one department had been given the top floor, and prevents separated elements from disregarding one another. As with the Salk Institute the emphasis on non-hierarchy is conducive to a collaborative attitude.

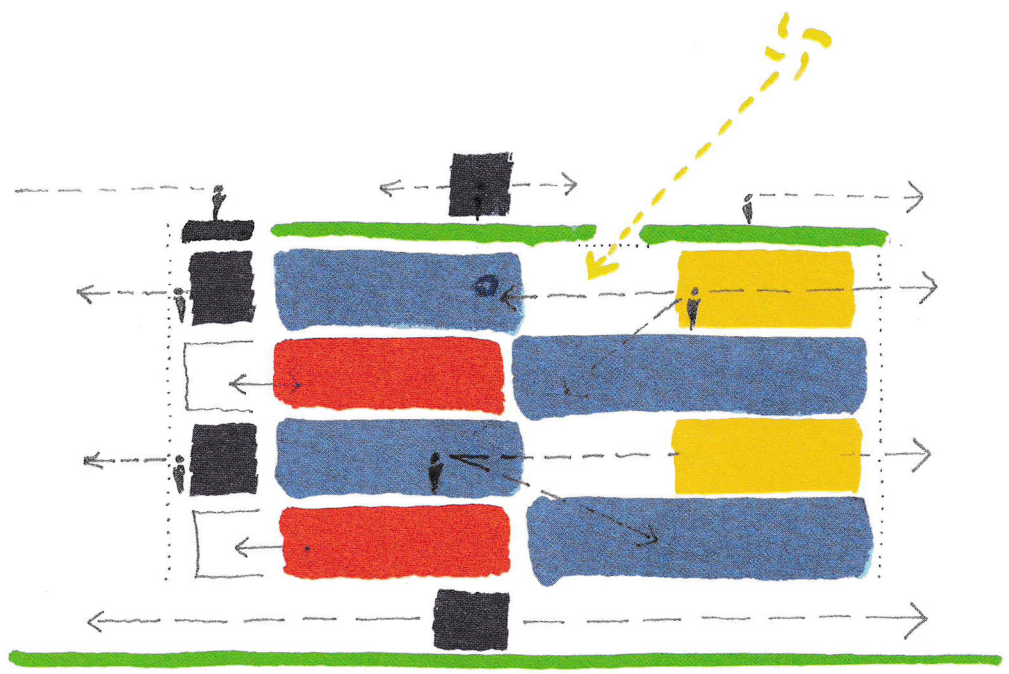


Figure 15:
Spatial relationship sketch by Ian Ritchie.

Figure 16:
Two storey laboratory space in the Sainsbury Wellcome Centre.

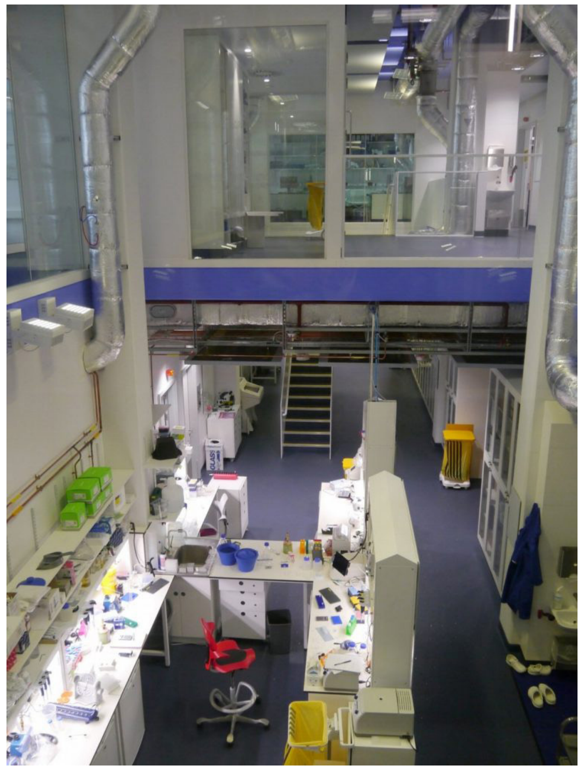


Figure 17:
Laboratory space in the Sainsbury Wellcome Centre viewed from above.

Subconsciously influenced connections have been derived from the subtle widening of circulation spaces, including corridors and stairways, to encourage the natural creation of informal meeting places by occupants. (Ferry, 2017, p.105). This provision comes as a response not only to Sainsbury's aims for the building, but as a response to witnessing the way individuals use the non-specific spaces in other laboratories. Combined with break out spaces at regular intervals with the aim of subtly pushing people together, these spaces capitalise on naturally occurring collisions and present the opportunity for them to be converted into longer conversations.

The social dimension was "at the heart of Ian Ritchie's thinking". (Ferry, 2017, p.102). This pursuit of a social dimension was firstly expressed in the aforementioned circulation and break out spaces, or so called "accidental spaces". (Ferry, 2017, p.102). Secondly, in the more structured tea points, cafes, and meeting rooms. These spaces were designated as "loose yet focal spaces" (Ferry, 2017, p.102), stimulating subconsciously influenced connections. These passive interactions help to break down perceived social barriers of approachability, opening the opportunity for fostering positive collaborations.

Extensive preparatory research underlies the success in the design of the Sainsbury Wellcome Centre. A relatively new building it is difficult to conclude if the centre will successfully adapt into the future demands of laboratory research. In theory the supporting services are in place, with exposed, accessible soffits allowing for changes without disrupting entire work flows. Conceivably this will not be the solitary measure of whether the building is successful, instead an evaluation of the built environments ability to achieve the aim of fostering a "collaborative ethos" through "frequent encounters between scientists", (Sainsbury in Ferry, 2017, p.6) should be of primary consideration.

Conclusion

Laboratories are an integral part of humanity's progress and innovation. They support society's growth, protection and development. Understanding the design of laboratories can foster progressive development of the infrastructure to support such fundamental endeavours. As research trajectories constantly change and evolve suggestion must be made that a lifecycle design approach is the only appropriate response. As demonstrated by the case studies analysed one factor can always be expected: the need for adaptability. A laboratory can only be successful if it can flexibly adapt into the future, providing a longevity to the design. The most explicit example of this is the Salk Institute for Biological Studies. This functional requirement can directly be applied to the model of the Living Laboratory, with one primary goal identified as following a lifecycle approach, with no end date. (ENOLL, 2022).

Overall there is a lack of empirical evidence to comprehend and support if spatial arrangement can influence the facilitation of cross disciplinary collaboration within laboratories. Conclusion, from observation, however can be drawn that encouraging interaction between individuals, both consciously encouraged and subconsciously influenced, is possible. A variety of methods are used by architects to attempt to foster collaboration within the built environment. The chief method is an emphasis on the facilitation of subconsciously influenced connections. Nudges indicate to users that the space they inhabit accommodates their encounters. These are implemented in the design of circulation spaces and journey routes, and evidenced in the proportion of the plan given to informal, non-specific spaces. Emphasis on non-specific spaces supports frequent encounters between individuals that transform into collaborative opportunities. Subsequently the analysis supports the need for non-specific spaces to be become a programmatic requirement in themselves.

Prominence of non-specific spaces and the utilisation of circulation routes can only be achieved if located strategically within the arrangement of the plan. The adjacency of programmatic requirements therefore plays an equally important role in the creation of interdependent connections.

Ultimately whether interaction can be engineered is a difficult attribute to measure empirically. Increasing contact between parties increases the likelihood of cross disciplinary collaboration. Consequently creating the opportunity to increase innovative output, when combined with adaptable, fit for purpose facilities.

Curating a collaborative ethos within a laboratory is arguably in part produced by its proponents. Each case study analysed has a key advocate asserting the agenda of cross contact. The evidence suggests that a positive working atmosphere, where all parties feel valued and are able to take ownership over the space, is conducive to a higher possibility of connection between parties. Allowing collisions to be capitalised upon.

If the future of research is co-creation (the cross collaboration between multiple parties including citizens and service providers) laboratory design must adopt principles that support cross disciplinary collaboration. The co-creation approach is best expressed in the concept of the Living Laboratory. This study suggests that the employment of non-specific spaces, articulated in both circulation and ancillary spaces, combined with appropriate spatial adjacency, can support the facilitation of cross disciplinary collaboration. These principles can be applied to the physical realisation of the Living Laboratory. Notably this is most successful when supported by a figurehead that can advocate for collaboration throughout the design process and post completion.

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