Supporting complex decision making in learning space design

Supporting complex decision making in learning space design: WDA-ANP, a novel sociotechnical systems approach

Eduardo Navarro Bringas

Institute for Sustainable Building Design, The School of Energy, Geoscience, Infrastructure and Society

Heriot-Watt University, Edinburgh EH14 4AS, UK.

Email: E.Navarro_Bringas@hw.ac.uk

Graeme Bowles

Institute for Sustainable Building Design, The School of Energy, Geoscience, Infrastructure and Society,

Heriot-Watt University, Edinburgh EH14 4AS, UK.

Email: G.Bowles@hw.ac.uk

Guy H. Walker

The School of Energy, Geoscience, Infrastructure and Society

Heriot-Watt University, Edinburgh EH14 4AS, UK.

Email: G.H.Walker@hw.ac.uk

*Corresponding author. Email: e.navarro_bringas@hw.ac.uk

Structured Abstract

Purpose:

The purpose of the paper is to introduce a novel approach, underpinned by systems thinking, to structure requirements and support front-end design decision-making around the performance in-use of developments within highly complex environments, with diverse stakeholders and users, such as the case of learning spaces in Higher Education (HE).

Research Design

Work Domain Analysis (WDA), a sociotechnical systems (STS) design framework, is first used to model the constraints that shape the expected performance of an informal learning space (ILS). Based on the model, the following stage involved a sector wide survey questionnaire (n=175) to appraise the views of different stakeholder groups in relation to ILS. These were analysed using the Analytical Network Process (ANP).

Findings

The study provides a novel approach, using WDA, to conceptualise the constraints shaping the performance in-use, integrating the perspectives of different stakeholder groups. Furthermore, it provides a structured approach to establish priorities that can serve as the basis to support complex decision-making during early design stages. The findings and proposed WDA-ANP approach aim to support HE estate managers on better understanding and integrating perspectives in relation to campus developments.

Originality/Value

In this paper, a novel systems-based approach is proposed as an alternative to conceptualise ILS. Furthermore, the approach is combined with ANP, a multicriteria decision-making approach, to develop a novel tool to derive priorities and support front-end design decision-making in learning space design.

Keywords: Learning Space Design, Front-End Design, Sociotechnical Systems, Work Domain Analysis, Analytical Network Process, Design for Operability, Design for excellence.

Introduction

The university campus, in particular, informal learning spaces (ILS), including university libraries, have undergone a great change, showcased in new spatial solutions such as, information and learning commons, learning hubs, or newly developed social study spaces (Walton & Mathews, 2019). With the turn into the new century, higher-education (HE) has undergone a transformation, driven in part by the widespread adoption of information and communication technologies, the favouring of socio-constructivist pedagogies, and the increasing focus on providing an excellent student experience to remain relevant (Beckers *et al.,* 2015). As a result, the university estate, originally developed to support teacher-centric and didactic pedagogies, has been the beneficiary of important investments targeting the adaptation of the physical environment to these new requirements. For instance, in the UK, the capital expenditure on the HE estate reached a record of 3.5 billion GBP during the academic year 2017-2018 (AUDE, 2019). While the research on school environments has developed a robust evidence base (Cleveland & Fisher, 2014), the physical spaces and facilities in HE have evaded the spotlight. Temple (2008, p. 232) signifies that the HE physical space is an under-researched area, stating '*further research is needed to illuminate the connections between space and institutional effectiveness'*. The issue is further illustrated by Ellis and Goodyear (2016, p. 151); '*if universities are to manage space to promote learning, then ways of conceptualising space are needed that ensure there can be strong connections between decisions about the design and management of space and the core activities of learning and teaching*'. Recent research in HE has predominantly focused on the effectiveness of innovative formal settings, also known as technology-enhanced active learning spaces (Brooks, 2011, Brown *et al.,* 2016). Furthermore, ILS, developed primarily to support self-directed learning have not been featured as predominantly, beyond research conducted from library services' perspective (Schader, 2008; Beagle, 2011; Walton & Matthews, 2013;

Johnson & Khoo, 2018). However, these spaces account for a high proportion of the capital investments and an increasingly higher share of gross floor area in recent facilities (Beckers *et al.,* 2015).

Another characteristic affecting the design of university spaces, in particular informal ones, is the wide variety and number of stakeholders involved in these developments. For instance, the issue of learning spaces development has been explored through the lenses of academic developers (Jamieson, 2003), of library services (Schader, 2008; Beagle, 2011), estates and facility managers (den Heijer, 2011; Riley *et al.,* 2015; Vidalakis *et al.,* 2013), architects (Boys, 2011), information services (Oblinger, 2006), or students (Harrop & Turpin, 2013; Wilson & Cotgrave, 2020). While the need for a collaborative approach in the development of HE spaces has been strongly promoted, the tensions between some of the perspectives above have also been highlighted (Boys, 2011; Brandt & Bachman, 2016; Walton & Matthews, 2019). Ellis and Goodyear (2016, p. 150) summarise it as; '*since there are great gulfs between the working practices of the main stakeholders – students, teachers, architects, campus infrastructure managers etc. no single model is likely to serve all current purposes. However, (…) the design, management and use of learning space should be a shared concern (…): a collective responsibility'*.

As made apparent by recent calls for a better understanding of spaces within HE, there is a need to explore new conceptual frameworks that can capture the complexities embedded within learning spaces. The present paper, through the application of systems theory, aims to propose a methodology to conceptualise the key factors shaping the operational performance of ILS, as well as assessing the degree of importance of these

factors from the perspective of different stakeholder groups. In the next section, the definition and scope of ILS as a sociotechnical system will explored. This is followed by a review of the two methodological approaches combined in the proposed WDA-ANP methodology, Work Domain Analysis (WDA) and the Analytical Network Process (ANP), are presented. The research methodology for the study, including the sampling and development of the questionnaire survey deployed are also covered. Finally, the results are shown and discussed, followed by the final conclusions, recommendations, and limitations of the study. The proposed approach is expected to serve as the basis for front-end design support tool, that can be used both to inform and assess early design concepts.

Literature Review

Conceptualising ILS as complex sociotechnical system

Within this paper informal learning spaces are defined as '*non-discipline specific spaces frequented by both staff and students for self-directed learning activities and can be within and outside library spaces'* (Harrop and Turpin, 2013 p. 59). The spaces considered as ILS are those that remain under the management structure of the HEI, excluding student halls, where the student largely manages their space and could be considered as their '*home'*. This definition covers many of the spaces that can be found in a present university, and a large part of the capital projects taking place in universities. These spaces have also been denominated as '*flexible'* spaces, peer-to-peer spaces, or social spaces (Oblinger, 2006). This definition offers insights of what is meant by '*informal learning spaces*', based on the general function for which spaces are primarily being developed. It is important to recognise that effectively these spaces complement

each other, and that the binary representation of formal/informal still fails to capture all the contextual nuances present across different campus developments (Boys, 2011).

The conceptualisation of the university learning environments as a complex system is a proposition that has been advocated, including ILS and even the entire campus. Such approaches aim to understand the campus infrastructure as a system of learning ecologies (Alexander & Price, 2012), or as a set of interconnected learning landscapes (Neary *et al.,* 2010). In the learning landscapes project tools to map the spaces on campus to the pedagogies and university mission and vision were developed. This tool, while it does not focus on particular designs, it offers universities a profile of their campus space and how it relates to the pedagogies that want to be promoted. Goodyear & Carvalho (2013), suggest the importance of mapping and understanding complex relations between artefacts, their affordances, and the learning situations, in order to design effective experiences, which is in turn applied to course design. Beagle (2011), clearly showcases what the implications of conceptualising ILS as a system are, that combines the physical form, the service, and of course, the inhabitants.

A commonality across the aforementioned positions refers to the view of campus operational performance as a complex emergent phenomenon. One that arises from the interactions between the different systems (physical design, technologies, services, curriculum) and the end-users of the university campus. Therefore, design considerations should acknowledge and try to untangle this complexity, rather than focus on designing each of the elements that form a learning environment isolated, in particular, to ensure maximal operational value for the relevant stakeholders and users. The systems approach aims to integrate and establish constraints that reflect stakeholder's values. This holistic approach, underpinned by systems thinking, in turn shares commonalities with the design

for excellence approach to design, in particular when it comes to supporting front-end design processes (Serugga *et al.,* 2020).

In this regard, recent research has discussed the relevance of Sociotechnical systems design and analysis frameworks to conceptualise different built environments as complex systems, including healthcare facilities (Hughes *et al.,* 2017), high-street designs (Stevens & Salmon 2014, Patorniti *et al.,* 2018), and even HE learning environments (Navarro *et al.*, 2020). In particular, Work Domain Analysis (WDA), a framework for the analysis of complex systems (Naikar, 2013), has been the most commonly deployed method in these contexts. WDA differentiates from other approaches to systems design in its focus on constraints and formative nature, this is, its focus lays on determining '*how activities and tasks can be conducted'* within the system (Vicente, 1999).

Research Methodology

Developing a WDA model

In WDA the functional structure of the system is modelled, using a set of hierarchical levels that connect the concrete objects and technology up to the broader purposes of the system (Jenkins *et al.,* 2009). Within this paper, WDA is used as the conceptual framework to model an ILS system, which will be used in the Analytical Network Process (ANP), to understand the priorities of different stakeholder groups in regard to the design of ILS.

In this case, as argued in the previous section, the performance in-use of a HE ILS is conceptualised through the systems modelling methodology WDA, which employs the Abstraction Hierarchy (AH) method for this purpose (Vicente, 1999; Naikar, 2013). The

abstraction hierarchy offers a theoretical framework to conceptualise sociotechnical systems, by enabling capturing constraints at various levels, with increasingly abstract purposes at the top and more concrete objects at the bottom. Furthermore, the nodes across levels are connected through means-ends relationships. For the ANP model, an extract of an ILS AH is used, referring to the top two levels in the framework; Functional purposes, and values, criteria and priority measures. These top two levels of the AH encompass what needs to be accomplished by a system (*i.e.* Functional Purposes) and how can we assess if this is being accomplished (*i.e.* Criteria, Values and Priority Measures). Therefore, if the focus is the understanding of what ILS are aimed to accomplish, and what aspects are prioritised, the conceptualisation and analysis of these two tiers is paramount.

For the higher levels of the system, the intentions behind the system are more likely elicited by stakeholders or general literature around systems of interest (Jenkins et al., 2009). For this study, a review of published ILS research and a case-study of an ILS development programme (undertaken between 2016-2019) within a UK university have been used. The programme includes the retrofit of a number of social spaces, a library retrofit, and a '*learning commons'*. Furthermore, together with the retrofit programme, a number of newly built learning spaces were also explored. The case study enabled the access to a range of stakeholders involved in the conception, design and early operation of the resulting learning space developments, which has enabled a good understanding of the context. In total, 15 semi-structured interviews were conducted and used as the basis to develop the WDA. The stakeholders were selected for their involvement and to include the perspective of different departments, including estates, library services, ICT services, design consultants, academics, and academic quality services. The model, once

developed, was refined through a workshop with four stakeholders, which also served to establish the means-ends connections across levels.

Proposed WDA-ANP methodology

The proposed methodology combines the previously described WDA approach (Naikar, 2013), used to develop the performance of ILS as a network, with the Multi-Criteria Decision-Making Analytical Network Process (ANP) (Saaty & Vargas, 2013). As a result, the suggested methodology provides a novel approach to conceptualise and support multi stakeholder perspectives during front end design stages of the project. The process followed to implement the suggested methodology is summarised in Table 2. The following section presents the main data collection method (*i.e.* survey questionnaire) used to develop the pairwise comparison matrices for the study.

[Insert Table 1 around this area].

Data collection for ANP: Survey questionnaire

The survey questionnaire to collect data for the ANP analysis was conducted digitally with representatives of UK-HEI. The total number of direct invitations directly sent was 683. The total responses collected were 186, of which 6 respondents indicated they had no experience in developing ILS, and another 5 were considered incomplete or invalid answers. As a result, a total of 175 valid answers have been further analysed, which accounts for a response rate of 25.6%. In terms of universities, there are a total 165 public HE providers currently operating in the UK (HESA, 2019). Within the 175 responses, 86 HEI were represented in the responses. Therefore, at least one valid response from 52.12% of UK universities was received. Moreover, the respondents were grouped based on the department they worked for; with library services (n = 75) and estates (n=65) being the most represented, followed by those working on learning and teaching (both

academics and professional services) (n=21) and ICT services (n=9). The response rate for the later groups is lower, which might be due to the difficulty of locating stakeholders directly involved in designing or managing learning spaces. While the remining of responses indicated they were external design consultants (n =1) or another group not included in the list (n=4). In relation to experience, a majority of the respondents (n=90) indicating more than 15 years' experience in HE, while, 17 of the respondents indicated less than 5-year experience.

Results

Resulting WDA model

Functional Purposes

[Insert Table 2 around here]

At the higher tier of the abstraction the '*raisons d'etre'* and the key constraints that need to be met by an ILS are to be included. Within the reviewed case-study, the stakeholder interviews revealed a number of key aspects to be included at this tier, which have been grouped into 6 broad themes, four primary purposes that the ILS is expected to contribute to, and two significant constraints to be met as to ensure a sustainable performance in-use (Table 2).

The key driver for the development of ILS at the institutions was the student experience, as students were suffering of a lack of study spaces, which was in turn affecting their overall experience, in some cases reducing the time spent on campus. Another important aspect mentioned, was the reputation enhancement that came with the development of this projects, in particular those that were expected to be used multi-purposefully, as both open study areas, but also to gather and host larger events for the HEI. Less prioritised at the time of conception, but still remaining as key considerations in the process, was the appropriateness and type of spaces and the social aspects of the spaces being designed.

An emphasis on spaces that could better support group and collaborative learning were aspects mentioned during the interview. This aligned with the overall graduate attributes, and learning strategy of the institutions, therefore, a purpose was framed as the development of an environment conducive to student learning and also the development of soft skills Furthermore, a final objective of these ILS, was to provide a place for meeting that could aid in making students feel part of the institution. targeting a demography of the students not taking part of clubs or societies.

Finally, two broad constraints that need to be met are also included at this level, these refer to the financial sustainability of the space, both in terms of operation and maintenance and servicing costs, and in terms of its commercial functions (hospitality, subletting or event organisation) from which the HE institution can obtain income. The latest constraints refer to the compliance with internal and external constraints, which include aspects of health and safety on the space, environmental performance targets and requirements, which might be imposed externally, regulations, norms, external institutions, or internally such as those derived by university's directives.

Criteria, values and priority measures tier

[Insert Table 3 around here]

This tier in the AH represents 'the criteria that must be respected for a system to achieve its purposes' (Naikar, 2013, p. 70), in other words, how the progress towards achieving the purposes can be measured. As discussed previously, the university is an intentional system - i.e. designed and constrained by cultural and social values, rather than natural laws. Thus, its design and performance are mostly largely shaped through cultural values and principles, and combines a set of measures, in some cases including difficultly

quantifiable values. Within the WDA model, 15 criteria and values, relevant to assess the performance of an ILS have been included (Table 3).

The first criteria are closely related to the purpose of providing an environment conducive to learning. Within Beckers *et al.* (2015) 'purpose-process-place' framework, these would refer to processes of individual (i.e. quiet or silent) learning, collaborative/group learning, or those learning processes enabled by technology. Within the studied ILS, it remained clear that design decisions were taken with these processes in mind, thus, their inclusion as a high-level tier in the model.

Furthermore, a set of more traditional estates and service management metrics were used in the case, which can be reflected by occupancy, environmental performance, financial measures, outcomes on the end-users (i.e. via satisfaction). Finally, other considerations, not that frequently measured with traditional metrics and more challenging to measure and largely subjective, were included in the model. Those refer to aspects such as the aesthetics, flexibility of use of these spaces, or aspects of recognition and visibility of the spaces. Through a workshop exercise, with 4 of the stakeholders involved in the interviews, the constraints included were validated and the means-ends connections were established across both levels. The resulting top 2 tiers of the WDA model used for the ANP analysis, are presented in Figure 1.

[Insert figure 1 around this area].

ANP results

Pairwise comparison matrices

The ANP results were calculated for the total of the respondents (n=175), and for each of the stakeholder groups for whom the questionnaire was directed; Estates & Campus services (n=65), Library Services (n=75), learning & teaching professionals and

academics (n=21) and Learning Technologists, AV and media services (n=9). As an example, a pairwise comparison for all the aggregated opinions (n=175) in relation to the Functional Purposes (FP) cluster, obtained through the process described in the method section, is showcased in Table 4. To obtain the pairwise comparisons across criteria and FPs the methods suggested by Kallas (2011) and Aragon *et al.* (2012) were followed. The remaining pairwise comparison matrices are computed for the criteria, as well as, for each of the stakeholder groups.

[Insert Table 4 around here].

Final priorities of the network

From the resulting limit super matrix, the priorities for the overall network and for each of the clusters can be derived. The localised priorities for both the "functional purposes" (FP) and the "*criteria, values and priority measures*" (C) clusters are presented in Table 5. An overall view of the priorities of all participants aggregated judgements is presented, while the judgements derived from each stakeholder group, estates, library services, academics (services and staff), and information services (ICT services) have also been aggregated separately.

[Insert Table 5 around this area].

Discussion

When looking at the priorities from the Functional purposes cluster, there appears to be some strong agreement across the 4 stakeholder groups surveyed, particularly in relation to the purpose of ILS, which their primary purpose appears to be to '*positively contributing to enhancing the on-campus student experience*' (FP2). This result aligns with the findings from Temple *et al.* (2014), who suggested the importance of the student-experience on almost all the decisions currently undertaken by UK-HEIs, particularly in

recent years, due to a number of government policy choices, particularly the removal of the existing recruitment cap of high-achieving A-level and the new tuition fee regime introduced in 2012.

In relation to the lowest priorities, all the stakeholders indicated that the constraints of *Compliance with requirements and regulations* (FP4) and *Economic Sustainability* (FP5) are the lower ranked considerations, which unsurprisingly, are not primary purposes of the ILS, but rather internal and external constraints that need to be met by the development for it to be able to operate in the first place (Naikar, 2013). These two functional purposes do not enhance directly the functionality of the space, while the remaining do so, by enhancing learning processes and the learning experience, which in turn can potentially impact broader university operations, such as student recruitment or academic results.

The biggest differences in terms of ranking amid the stakeholder groups appear to be on the remaining functional purposes – *Providing an environment conducive to learning and attainment of life skills* (FP1), *Fostering a sense of community* (FP3) and *Reputation Enhancement for the HEI* (FP6). The provision of a learning environment is ranked second by library services and ICT/AV services, which tend to be the ones operating the space, however, academics and estates tend to favour the community aspect and the reputation enhancement respectively. The slightly lower prioritisation result from the academic stakeholders appears surprising, however, it is consistent with the emphasis on socio-constructivist learning principles, that have shaped library retrofits or ILS developments, like Information and Learning Commons (Walton and Matthews, 2019). This appears to be further reinforced by the high prioritisation, from academic stakeholders, of criteria and principles associated with assessing and promoting the sociality of the spaces.

In relation to the criteria, there is also a wide agreement in relation to the most important aspects of an ILS, with all the stakeholder groups selecting the provision of a psychologically and physically safe environment (C12), and also prioritise highly the provision of a comfortable indoor environmental quality (C4). Based on the hierarchy of user needs (den Heijer, 2011), safety and comfort, together with pervasive network access, are considered the basic needs that users of HE spaces have. While other criteria like aesthetics, or social aspects would target needs of a higher order in Maslow's hierarchy. Thus, it is not unexpected that they are considered so fundamental. Furthermore, research on the most important factors affecting user's performance in offices, also suggests that Indoor Environmental Quality (i.e. thermal, acoustics, visual, and air quality), are heavily prioritise by end-users themselves (Middlehurst *et al.,* 2018).

The biggest difference appears in relation to student satisfaction (C15), which is highly prioritised by most stakeholder groups, with the exception of the academic's group, where its prioritisation is slightly lower in fifth, below the 'social' criteria , both in reinforcing social interactions (C13) and enabling collaborative learning processes (C3). As seen before, this is consistent with the previously addressed emphasis on community stated in the functional purpose. Furthermore, there is also a clear agreement on the bottom aspects featuring costs (C5) as a low priority, and income generation as a marginal criterion (C9). Unsurprising, taking into account that HEI are non-profit, and most of their income is generated through tuition fees and research grants, depending on the HEI being either teaching or research oriented (Temple *et al.,* 2014; AUDE, 2019).

Amid the lower ranked criteria, surprisingly, there is flexibility and adaptability (C8), which is an aspect featured frequently in recent learning space design literature, which calls for developing designs that can adapt to and support multiple learning activities and styles (UCISA, 2016). However, flexibility is a difficult to define criterion, as it often

results in sacrifices over the main purposes for which a space is designed. Another lower ranked criterion is the maximisation of occupancy, usage and access of the space (C1), which was expected to be featured more highly in the list, as occupancy and use, in terms of heads counts and business, was identified throughout the interviews as an important measure for the success of ILS, and it is an important metric on traditional estate and space management.

In relation to the learning processes, an important purpose in the development of ILS in the first place, there is a tendency to favour spaces focused on promoting collaborative learning processes (C3), closely followed by digital and technology enabled learning processes (C6). When it comes to 'modern' learning spaces recent research (Oblinger, 2006; Beckers *et al*., 2015) argues that student-centred pedagogies and ICT developments, in relation to the pervasive access to resources, as the biggest factors in shaping retrofits at existing university estates (e.g. library redevelopments, commons, crush spaces…). Consequently, the findings align with these views, where individual learning processes (C11) appear to be prioritised lower in comparison to the processes.

Conclusion

As shown argued in the study, and through application of the proposed WDA-ANP methodology, HE institutions can be conceptualised as complex and often large sociotechnical systems. Thus, it is not surprising to find that research on learning space development highlighted problems with multiple, and sometimes conflicting perspectives, to what can be equated to a '*silo mentality'*. This is quite reminiscent within recent research around learning space design and evaluation, where spaces and the overall estate is discussed from the lenses of different groups, such as academic developers, estate managers, and architects themselves, as well as from students or learning technologists.

Moreover, recent toolkits and guidelines, emphasise the need to involve, account for, and understand different stakeholders and their needs, which often required different considerations. The WDA-ANP process proposed in this paper offers a structured approach to untangle the complexity and requirements behind the views of different stakeholders and decision-making groups. In this case, the approach provides the means to integrate perspectives and criteria from different groups in a single model to guide decision-making. The approach is contingent to the context of the university, enabling to capture particular institutional requirements or requirements specific context of operation of the facility being designed. Moreover, it allows not only to understand the priorities of different groups, but also provides a structured approach to quantify and aggregate them so more balanced design decisions can be taken. In the studied case, the perspectives and priorities from university stakeholders involved in developing and operating ILS, appear aligned in regard to the most relevant and least relevant priorities, although some differences arise across the intermediate priorities. There appears to be a solid common ground and understanding across stakeholders on the purposes of ILS, and what they aim to accomplish, including the learning processes and services that should be prioritised within them.

Recommendations of the study

All in all, the application of the ANP approach, combined with a sociotechnical systems design framework, like WDA, should not overly focus on the final design solution. The process of developing a model relevant to the HE can serve as a framework to clarify needs and priorities of decision makers, as it allows to untangle and structure the complex design problems at hand. Moreover, the holistic nature of a systems approach, such as WDA, enables the integration of multiple views and perspectives from the onset of the project. Thus, the proposed WDA-ANP offers a structured framework for learning space

developers to articulate the needs and priorities from different stakeholders into a single model. All in all, the process of development of the model and the prioritisation offer tools to supplement the existing toolkit available for early project briefing of HE learning spaces. Moreover, while not explored in this study, the ANP, as Multi-Criteria Decision-Making tool, offers a powerful tool for space developers to evaluate, compare and rank multiple design concepts and proposals.

While the context of research has focused on HE facilities, similar applications on other urban contexts (Patorniti *et al*., 2018), appear to indicate that a sociotechnical systems approach offers promising venues to supporting a wide range of design problems within the built environment. Therefore, future studies deploying the proposed methodology can focus on other complex facilities that cater for the needs multiple and varied users (*E.g.,* major transport hubs, co-location offices, outdoor urban spaces…). Moreover, following the representation of the functional performance as a complex STS (and an intertwined network) the deployment of social network analysis representations and metrics (*e.g*. centrality measures…) can also be used in decision-making and assessment for these spaces. Moreover, other well-established system methodologies, such as general systems thinking, and system dynamics can also offer new of ways of supporting designers and decision-makers during the front-end design and management of facilities.

Limitations of the study

While careful consideration was placed both on the design, analysis, and overall research process. The research study does, however, have some limitations. First, the choice of Likert-scale type questions instead of the pairwise comparison type questions for conducting ANP (Saaty, 1996), which might have resulted in different results from the analysis, such as prompting stronger judgements on the priorities, or introduce a higher

degree of inconsistency to the matrices (Kallas, 2011; Aragon *et al.,* 2012). The choice was taken to promote a higher response rate and involvement from stakeholders, as the Likert-style questionnaire is considerably shorter than the pairwise-style questionnaire: 39 questions versus 96 questions. Furthermore, the reduced sample of respondents from some of the stakeholder groups, in particular the perspective of academics (*e.g.* professional services, Pro-Vice Chancellors or deans for learning and teaching matters), or ICT professionals which they are frequently involved in developments, might not allow to infer strong conclusions from the priorities from those groups. Particularly, in contrast with library services and estates professionals, which responded the questionnaire in larger numbers. Finally, the perspective of other stakeholder groups, could be further explored in future studies, in particular design consultants and architects specialised in the design for HE facilities and spaces. Moreover, the perspective of students, from student representatives involved in project steering or committee meetings would bring an alternative perspective. In any case, Wilson & Cotgrave's (2020) recent study suggests that similar criteria *(e.g.* centred on functionality for learning/task or resource availability and access) might also be priorities by university students.

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Table 1 WDA-ANP methodology proposed to support front-end design decision-making in Learning Space design

Steps of WDA-ANP	**Description of the steps/processes to be undertaken**
Step 1: WDA Model Development	Model development using Work Domain Analysis (WDA) framework, a theoretical framework developed in the field of Human Factors that can be used for conceptualising complex STS. The resulting abstraction hierarchy model's higher tiers (Figure 1) serve as the basis for the ANP. In order to develop a WDA, existing published guidance and literature on the systems under study or interviews and workshops with subject matter experts are suggested (Jenkins *et al.,* 2009; Naikar, 2013). For the development of the ILS model, a literature review and a qualitative case-study approach of an ILS programme (2016-2019), through 15 semi-structured interviews with relevant stakeholders, have been undertaken.
Step 2: Data collection for the ANP	Collecting the views around a set of defined constraints (based on the WDA) from different stakeholder groups involved in ILS design or operation within UK HEIs (n=175). Questions using a Likert-scale modelled on AH connections and constraints (figure 1). The use of Likert survey questions as inputs for ANP follows the recommended approach from Kallas (2011) and Middlehurst *et al.* (2018).
Step 3: Pairwise comparison matrices	Developing pairwise comparison matrices based on survey results. To use Likert-scale as inputs for the pairwise matrix, the survey questionnaire was modelled based on the approach suggested and described by Kallas (2011) and Middlehurst *et al.* (2018). The questionnaire results are used in the pairwise comparison matrices by comparing the values resulting between different criteria. To ensure validity of the results, pairwise comparison matrices require consistent inputs from stakeholders, for this the Random Index and Consistency Rating tests proposed by Saaty (1996) were used. In this study, a questionnaire

	answered by several stakeholders across various HEI is used as the input for the matrices. Thus, a number of individual opinions were collected. In this case, the first option is selected following the Aggregation of Individual Judgements (AIJ) approach indicated by Middlehurst *et al*. (2018) and Aragon *et al.* (2012). The values of the Aggregated (A) matrix are computed through the geometric mean of all the values within each respondent matrices. The resulting aggregated matrix (A) is then used to derive the eigenvector (*w*). The eigenvector contains the priority values for each criterion in the pairwise matrix, which later are entered into the super-matrix (W), for the whole network.
Step 4: Deriving priorities (per stakeholder group)	Once the priority vector/eigenvector (*w*) of each aggregated pairwise comparison matrix is calculated, the next step is the development of the Supermatrices (W), which are used to derive the overall network priorities. The unweighted Supermatrix is developed by inputting the priority vectors (*w*), with respect to the elements that they are related to. Finally, the limit supermatrix, which can be used to determine the final priorities, is obtained by raising the initial supermatrix to powers by multiplying it many times itself. The final priorities for each of the criteria and purposes of the ILS are derived from the limit supermatrix (Saaty & Vargas, 2013).

Table 2 Identified constraints at the FP tier of the WDA model

Code of constraint	Description of constraint	Case-Study - Covered by stakeholder group						References
		L&T Academic	L&T Prof. Services	Library Services	Estates	IS & AV Services	External Consultants	
FP1	Provide an environment conducive to learning and attainment of life and work skills.	√		√	√	√		den Heijer (2011); O'Neill & McMahon (2005); Neary *et. al.* (2010); Radcliffe *et al.* (2008); UCISA (2016)
FP2	Positively contribute to enhance the '*On-campus'* student experience		√	√	√			Temple *et al.* (2014); JISC (2006); Oblinger (2006); Kariippanon *et al.* (2019)
FP3	Promote a sense of identity and community	√			√			Temple (2008); Appel-Meulenbroek *et al.* (2011); Bryant *et al.* (2009); Radcliffe *et al.* (2008); Walton & Matthews (2013)
FP4	Compliance and alignment with institutional requirements, & external standards			√	√	√	√	den Heijer (2011); Bryant et al. (2009); Radcliffe et al. (2008); UCISA (2016)
FP5	Financial sustainability of the learning environment	√		√	√	√	√	Vidalakis *et al.* (2013)
FP6	Reputation enhancement and visibility for the HEI		√		√			Price *et al.* (2003); Neary *et al.* (2010); Temple *et al.* (2014); Bligh & Pearshouse (2011); JISC (2006)

Table 3 Identified constraints at the CVPM tier of the WDA model

Code of constraint (WDA Model)	Description of constraint	Case-Study - Addressed by stakeholder group						References
		L&T Academic	L&T Prof. Services	Library Services	Estates	IS & AV Services	External Consultants	
C1	Aesthetic Value and Condition of Facilities			√	√	√		AUDE (2019); Wilson & Cotgrave (2020); Price *et al.* (2003)
C2	Awareness and recognition of facilities		√		√			Price *et al.* (2003); Neary *et al.* (2010); Temple *et al.* (2014); Bligh & Pearshouse (2011); JISC (2006)
C3	Support collaborative and social learning	√		√	√			O'Neill & McMahon (2006); Kolb & Kolb (2005); Beckers *et al.* (2015); Scott-Webber (2004); Boys (2011); Oblinger (2006)
C4	Provision of optimal (comfortable) environmental parameters			√	√	√	√	Middlehurst *et al.* (2018); Vischer (2008)
C5	Operation and maintenance costs			√	√			Oblinger (2006); Radcliffe *et al.* (2008); Vidalakis *et al.* (2013)
C6	Support technology-enhanced and digital learning		√	√		√	√	JISC (2006); Beckers *et al.* (2015); Radcliffe *et al.* (2008); UCISA (2016); Oblinger (2006)
C7	Environmental performance metrics				√		√	Middlehurst *et al.* (2018); Vischer (2008)
C8	Flexibility and adaptability of spaces and resources			√	√	√	√	Appel-Meulenbroek *et al.* (2011); Boys (2011); Temple (2008); Vischer (2008)
C9	Income Generation (Related to the facilities, services and spaces)			√	√	√		AUDE (2019)
C10	Maximise occupancy and usage (of the facilities and resources)		√	√	√	√	√	SMG (2006); SCONUL (2016); Pearshouse *et al.* (2009); Boys (2011)
C11	Support reflective and cognitive learning	√	√	√		√	√	O'Neill & McMahon (2005); Boys (2011); Kolb & Kolb (2005); Beckers *et al.* (2015); Scott-Webber (2004)
C12	Provide a safe environment (Psychological and physical)				√		√	Kariippanon *et al.* (2019)
C13	Opportunities for social interaction	√		√	√		√	Scott-Webber (2004); Temple (2008); Beckers *et al.* (2015)
C14	Staff satisfaction: Professional services related to the space				√		√	
C15	Student satisfaction (with facilities and resources provided)	√	√	√	√	√	√	Vischer (2008); Bligh and Pearshouse (2011); Matzdorf & Greenwood (2015); Pearshouse *et al.* (2009); Vidalakis *et al.* (2013); Price *et al.* (2002)

Table 4 Aggregated matrix of all valid answers (n=175) and priority vector (w) for the Functional Purpose's cluster

		FP1	FP2	FP3	FP4	FP5	FP6	Eigenvector (*w*)
λ_{max} = 6.00 CI = 0.004 RI = 1.24 CR = 0.03	FP1	1	0.632	1.714	1.856	1.022	1.131	0.180
	FP2	1.582	1	2.639	2.851	1.703	1.857	0.286
	FP3	0.583	0.379	1	1.150	0.619	0.674	0.107
	FP4	0.539	0.351	0.870	1	0.545	0.596	0.096
	FP5	0.979	0.587	1.615	1.836	1	1.107	0.173
	FP6	0.884	0.538	1.484	1.677	0.904	1	0.158

Table 5 Normalised priorities, for the Functional Purposes and Criteria clusters, for the different stakeholder groups.

	All Answers (n=175)		**Estates (n=65)**		**Library (n=75)**		**Academics (n=21)**		**ICT/AV services (n=9)**	
	Local Prior.	Ranking	Local Prior.	Ranking	Local Prior.	Ranking	Local Prior.	Ranking	Local Prior.	Ranking
FP1	0.17965	2	0.1503	**4**	0.20411	2	0.17123	3	0.18134	2
FP2	0.28583	1	0.29121	**1**	0.27692	1	0.30286	1	0.30251	1
FP3	0.17349	3	0.16796	**3**	0.16176	3	0.24597	2	0.13118	4
FP4	0.09579	6	0.09993	**6**	0.09769	6	0.07557	6	0.11314	6
FP5	0.10739	5	0.11014	**5**	0.10438	5	0.09344	5	0.13052	5
FP6	0.15785	4	0.18046	**2**	0.15514	4	0.11092	4	0.14130	3
C1	0.08448	5	0.09158	**5**	0.08678	4	0.07153	6	0.08202	4
C2	0.06071	7	0.06180	**7**	0.05797	8	0.06233	7	0.04652	9
C3	0.07268	6	0.07024	**6**	0.06681	6	0.10251	4	0.06864	6
C4	0.12235	3	0.11588	**3**	0.12867	3	0.11877	3	0.13367	2
C5	0.01921	14	0.01992	**14**	0.01778	14	0.01867	14	0.02648	14
C6	0.05820	8	0.05514	**8**	0.06297	7	0.05565	8	0.05890	8
C7	0.04540	10	0.04955	**10**	0.04246	11	0.03729	12	0.06350	7
C8	0.03227	13	0.02896	**13**	0.03468	12	0.02835	13	0.03543	12
C9	0.00697	15	0.00951	**15**	0.00518	15	0.00693	15	0.00796	15
C10	0.04787	9	0.04977	**9**	0.04833	9	0.03786	11	0.04370	11
C11	0.04453	11	0.04189	**11**	0.04606	10	0.05161	9	0.04477	10
C12	0.14410	1	0.13460	**1**	0.14966	1	0.14372	1	0.15157	1
C13	0.09314	4	0.09645	**4**	0.08023	5	0.12292	2	0.07773	5
C14	0.03721	12	0.04108	**12**	0.03071	13	0.04837	10	0.02794	13
C15	0.13086	2	0.13364	**2**	0.14172	2	0.09348	5	0.13118	3

Figure 1 Resulting Abstraction Hierarchy of an ILS (Higher level tiers)