Embracing complexity

Embracing complexity: A sociotechnical systems approach for the design and evaluation of higher education learning environments

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Higher education institutions (HEI) have undergone fundamental changes driven by ICT developments, globalisation, and the advent of socio-constructivist pedagogic approaches. As a result, within the UK, capital investment in new and retrofitted facilities has reached a record expenditure. Recent research on user-related evaluations of facilities, particularly in HEI learning spaces, highlights the prevalence of evaluations dominated by reductionist approaches focused on measuring user's outcomes, such as satisfaction, learning outcomes or engagement. These approaches have a major pitfall, neglecting the complexity of the dynamic relationships between people, spaces, technology, institutional structure and pedagogic practices. In response, this paper aims to propose a shift on current approaches by exploring the application of sociotechnical systems theory to learning space design and evaluation. Amid these, it is argued that Cognitive Work Analysis (CWA) offers promising alternatives to inform design and management of higher education learning spaces. Finally, within the paper, three CWA interventions are proposed and discussed, focusing on how these address previously identified shortcomings of predominant approaches used in HEI learning space design and evaluation.

Keywords: Post Occupancy Evaluation, Learning Spaces, Higher Education Institutions, Sociotechnical Systems, Cognitive Work Analysis.

Relevance to human factors theory:

Dominant approaches used in higher education space evaluation appear largely deterministic and dominated by focus on user outcomes. However, the relationships between the campus environment and its users, include multiple characteristics of complex sociotechnical systems. The application of CWA within this novel domain is suggested, and its implications and potential interventions are discussed.

Introduction

An overarching reason for built environment's existence is to support and structure the activities and tasks performed by the users that inhabits it (Vischer, 2008; Alexander, 2008). In spite of this, built environment research has focused mostly on the building process and the financial considerations associated with operating buildings, until recently, when research in corporate real estate management and facilities management has emphasised the value-in-use of facilities and people-centred practices (Lindahl et al., 2012). From an economic perspective, physical spaces are at the very least a 'necessary evil' for an organisation, often the second largest expense, yet with the potential to support the organisation and its members on their activities and contribute to its overall performance (Becker, 1990). Therefore, facilities performance should be assessed, amid other factors, in relation to how well, or not, they support organisations and end-user's needs and goals through their daily practices and activities (Blakstad et al., 2008). Design quality of buildings in-use has been assessed within three dimensions; social, economic and environmental. While a variety of tools and criteria have been developed for assessing both economic and environmental performance, tools for assessing social performance in-use remain scarce. Appraisals of the social design quality of buildings have prioritised the measurement of user outcomes (e.g. satisfaction, productivity, performance etc.) over understanding dynamic relationships between spatial designs and users, while they interact and use buildings (Watson et al., 2016).

According to the logic presented above, Higher Education (HE) facilities at a fundamental level should support the purposes of the institution's they host. This includes supporting their learning, teaching and research activities. In recent years, the sector has undergone major changes driven by ICT developments such as, technology-enhanced learning initiatives, globalisation, and the rise of new pedagogic approaches, which challenged traditional behaviourist cognitivist views of learning, known as socio-constructivist pedagogies promoting cooperative-learning, active-learning, and a more student-centric approach to learning and teaching (Becker et al., 2015). Although these changes, especially ICT developments, have been presented as a threat to the physical campus, in truth, the capital investment in newly built and retrofitted facilities, at UK universities, has reached a record expenditure of 3 billion GBP in the academic year of 2015-2016 (AUDE, 2017). To ensure accountability, a set of key performance indicators have been established with the aim to measure both investment and space efficiency, and at a lesser extent, quality, sustainability and value of campus estates (AUDE, 2017). Yet, these spatial and economic indicators still fall short in assessing the impact on end-user's daily activities, or how buildings enable the functions and purposes for which they are designed (Temple 2008; Cleveland and Fisher, 2014).

The paper sets out to discuss how the application of Sociotechnical Systems (STS) approaches to design and evaluation in the context of HE offer opportunities to address some of the shortcomings identified in dominant approaches used in HE campus developments. First, the approaches to evaluation and design of facilities and learning spaces, particularly those used in HE, are reviewed, highlighting current limitations and trends. Afterwards, an overview of previous STS design and analysis approaches in architectural design and similar complex domains is presented. This is followed by, a discussion of the context in which Higher-Education Institutions operate, which this paper argues, it is an environment comparable to that found in complex STS. Finally, the paper proposes and discusses three interventions based on Cognitive Work Analysis (CWA), a robust STS design methodology, that offer new directions and opportunities to complement and address identified shortcomings in existing HE learning space design and evaluation approaches.

Evaluation of learning and teaching spaces and facilities in Higher-Education

In the built environment, Post Occupancy Evaluation (POE) has served as the umbrella term to group evaluations of buildings in-use, which included occupant's perspectives. The origins of POE in the 60s have been strongly linked to environmental psychology and environment-behaviour research, primarily used in care facilities, such as mental hospitals, in which the effects of the environment on patients' mental states was of utmost concern (Preiser, 1995). However, during the 90s and early 00s, POE pivoted towards a more predominant focus on energy performance and occupant satisfaction led by the PROBE studies and the development of standardised satisfaction surveys such as, Building in Use Survey (Leaman and Bordass, 2001). Hadjiri and Crozier (2009) defined POE as "*a process that involves a rigorous approach to the assessment of both the technological and anthropological elements of a building in-use*", emphasising the usage of the building and encompassing technical and social aspects that directly affect users. Building evaluations can be undertaken at different points of facilities lifecycle, depending on the aim for which the evaluation is envisioned – i.e. fixing current facility, selecting best-fit among potential facilities, inform programming/briefing or generating knowledge (Kernohan et al., 1992). The benefits and rationale behind conducting POE have been thoroughly discussed in the literature (Preiser, 1995; Zimmerman and Martin, 2001; Hadjri and Crozier, 2009; Whyte and Gann, 2001). According to Zimmerman and Martin (2001), an '*overarching benefit from conducting POE is the provision of valuable information to support the goal of continuous improvement*', positioning POE as a critical step to establish a continual improvement cycle, both for management and design. Following this logic, the latest version of the Royal Institute of British Architects' Plan of Works (RIBA-PoW) (2013), UK's standard project lifecycle framework, features POE strongly during initial and latest stages of the framework (i.e. design and occupancy). Other roles attributed to POE, include the view as '*tool for thinking*' which attempts to bridge the communication gap between occupants and providers, as it can facilitate improvements on organisational performance through the involvement of its members in building projects (Kernohan et al., 1992; White and Gann, 2001). User-related studies in the built environment can be positioned within a continuum between deterministic, where the environment can condition user's behaviours, and socio-constructivists approaches, where environment's effects are minimised in favour of social factors (Vischer, 2008). Although deterministic models signified by satisfaction surveys are prevalent (Watson et al., 2016), in recent years, other approaches have pointed the importance of assessing user activities and practices. Examples include, propositions for sociotechnical POE (Chiu et al., 2014; Lowe et al., 2017), more holistic evaluations of performance (Hay et al., 2018), or for introducing assessment concepts used in other disciplines, such as the interactive adaptability between inhabitants and their surrounding environment (Cole et al., 2008), or usability (Alexander, 2008). These approaches tend to share a similar underpinning, which encourages to view the user/organisational interaction with the built environment as an indivisible system. The latest concept is further clarified by Lindahl et al. (2012) as '*a cultural phenomenon that can only be improved by understanding user experience, considered as situated action in a specific context*'. Furthermore, the built environment is viewed as a process, rather than a finalised product, that adapts over time, through interactions with users, organisational structures, and information technologies (Lindhal et al., 2013). Table 1 offers an overview of predominant building evaluation processes and POE approaches applied in the HE sector.

[Insert Table 1 around this area].

In HE, the design of learning spaces has received an increasing attention from disciplines and researchers not traditionally involved in space design, such as technologists and education researchers (Oblinger, 2006; Temple, 2008; Radcliffe et al., 2008; Pearshouse et al., 2009). This renewed interest can be linked with the developments in Information and Communication Technologies, and the new learning opportunities they afford, and the increasing prevalence of socio-constructivist views of learning, including an increasing interest on pedagogic practices around active, problem-solving, student-centred and collaborative learning. Related to the design of innovative spaces to accommodate these practices, a renewed research interest on learning space design and evaluation has been revitalised since the early 2000s (Table 2).

[Insert Table 2 around this area].

These studies tend to share similar findings regarding the limitations of current approaches to POE. For instance, they showcase how existing approaches largely fall short in understanding the complex nature of the relations between the individuals, their performance and the multiple factors shaping the environment, including organisational, social, physical and virtual spaces (Hunley and Schaller, 2005; Temple, 2008; Bligh and Pearshouse, 2011; Lee and Tan, 2011). These findings resemble the ones from studies based on non-academic contexts of use such as, offices (Vischer, 2008; Lindahl et al., 2012), healthcare (Watson et al., 2016), or domestic retrofits (Chiu et al., 2014; Lowe et al., 2017). At a wider scale, the entire campus, Den Heijer (2011) discusses the role of real estate interventions in adding value to an organisation and its users. The findings showcase a similar issue when trying to assess the direct effects arising from estate interventions onto the institution, as these interventions frequently encompass changes in other production factors such as, changes in work practices or ICT upgrades. Therefore, isolating real estate interventions to assess their added value often results in futile efforts. In this context, Den Heijer (2011) suggests the view of organisational performance as emerging from the interactions between 5 resources; human resources, information, capital, technology and real estate. Among these, human resources are the key asset of the university, as its main outputs for society are '*knowledge and (potential) knowledge workers'* (Den Heijder, 2011).

Lastly, Temple (2008) and Cleveland and Fisher (2014), in their critical reviews, propose a path forward to advance research in the field of design and evaluation of campus development in Higher-Education:

(1) Development of rigorous methods that can be used to assess the effectiveness of physical learning environments in supporting desired teaching and learning practices, activities and behaviours (Temple, 2008; Cleveland and Fisher, 2014).
(2) Promote interdisciplinary research involving a variety of academic disciplines, amidst others, education, human geography, environmental psychology and architecture (Cleveland and Fisher, 2014).
(3) Development of formative evaluation methodologies, that could support evaluation through the lifecycle, starting from early concepts (Cleveland and Fisher, 2014).

Human Factors and sociotechnical systems: A complementary approach for learning space and campus design?

In their review, Dul et al. (2012) denote three fundamental characteristics differentiating HF from other research disciplines; 1) its '*systems focus*', 2) its '*design-driven*' nature, and 3) its focus on outcomes that '*jointly optimise both, people's well-being and system's performance',* thus combining both user and business perspectives. HF and its methodological frameworks developed for designing and analysing complex STS, can complement previously discussed limitations underlined by learning space research in HEIs.

HF and architecture are not complete strangers to each other, especially, in the domain of hospital design, ergonomics and particularly participatory ergonomics, have shaped the architectural design of hospitals (Villeneuve, 2000; Remjin, 2006). In other contexts, architects have made use of HF, for instance, featuring task analysis to understand how users attain their goals within built environments (Attanesse and Duca, 2012) or focusing on the design of the furniture they interact with in learning environments (Parvez et al., 2019). These approaches, with rare exceptions (Robertson and Courtney, 2004), fail to address organisational goals and structures, focusing mostly on the micro interactions of users with their immediate environment. Another area in architecture associated to HF is '*universal design*', a design paradigm concerned with ensuring spaces are both accessible and usable by people with distinct physical, psychological and sensorial disabilities (Preiser & Ostroff, 2001; Iwarsson & Sthal, 2003). Furthermore, architectural design frameworks (e.g. RIBA- PoW) and ergonomic interventions appear to be complementary approaches, however, they showcase a few differences. Architectural design is commonly structured as a top-down approach, commencing broadly and narrowing into increasingly specific and detailed designs as projects advance, starting from strategic goals, moving then to forms and layouts, and then progressively to the building systems, elements and components. Meanwhile ergonomic interventions, due to their focus on joint-optimisation (well-being and system performance), combine both a top-down approach, focused on setting business goals and objectives of the intervention, with a bottom-up approach, including detailed studies of users and activities to be supported (Remjin, 2006). From these approaches it appears that ergonomic interventions would have the highest contribution into the architectural process during early stages, feeding requirements into briefing and early concept designs (Attanese and Duca, 2012).

In the context of learning environments, recent years have led to the study of the environment as a system, and how the interactions within them can lead to effective learning experiences. Goodyear and Carvalho (2013), suggest the importance of mapping and understanding the complex relations between artefacts, their affordances, and the learning situations, in order to design effective experiences. Shapiro et al., (2017) suggest an interaction geography methodology, underpinned by human geography and interaction analysis, which serves to map and understand users' experiences and interactions, with the environment and other users, across time and space within museums. Similarly, in the context of academic libraries, Johnson and Khoo (2018) explore patterns of individual and group interactions across time and space. These methods are valuable in designing and understanding user-environment interactions, however, these can be further complemented by a greater understanding of the organisational and macro constraints that shape HEIs.

In recent years, HF has increasingly engaged with issues of a complex nature, which has showcased the need to develop methods to study these systems and by broadening the boundaries of analysis (Salmon et al., 2017). This shift is reflected by the number of interventions being applied in domains not traditionally featured in HF, for instance, development of military doctrine/strategy (Naikar, 2017), analysis of outdoor activities (Carden et al., 2017), urban planning and city design (Stevens and Salmon, 2015; Stevens et al., 2018; Patorniti et al., 2017), analysis of performance in sports (McLean et al., 2017), or design of sustainable workplaces and buildings (Lowe et al., 2017). A number of HF frameworks that support holistic and multi-layered analysis of systems have been developed, for instance; cognitive work analysis (CWA) (Rasmussen et al., 1994; Vicente, 1999), the event analysis for systemic teamwork (Salmon et al., 2017) or the STS framework (Davis et al., 2014).

According to Read et al. (2013), four are the characteristics consistent among the approaches underpinned by systems theory: (1) the concept of emergence, originated from the interactions and non-linear relationships between components. (2) They recognise the variable performance and behaviours within the system and its components; therefore, they aim to describe a range of behaviours, rather than predicting them, and acknowledge that unanticipated behaviours are frequent. (3) Systems approaches recognise the dynamic nature of systems, as these evolve over time. Finally, (4) they view systems as hierarchical structures; therefore, focusing not only the physical or technical aspects, but also taking into consideration other aspects shaping organisations – e.g. culture, social structures, regulations, policies or strategies. These characteristics are rarely featured in studies of building's performance in-use, although recently, examples featuring some of these principles have started to arise, such as previously mentioned studies of occupant adaptations (Chiu et al., 2014; Lowe et al., 2017), or the '*usability of workplaces'* studies (Alexander, 2008; Blakstad et al., 2010), or the research on the interactive adaptability between occupants and the surrounding environment (Cole et al., 2008).

Analysis of sociotechnical systems with CWA: Domains and applications

Cognitive Work Analysis (CWA) is a framework originally developed by Rasmussen to analyse and design complex sociotechnical systems (Rasmussen et al., 1994; Vicente, 1999; Jenkins et al., 2009). It promotes and recognises the need to design for user adaptation, rather than trying to prescribe ideal behaviours, as in complex environments uncertain/unexpected events are frequent. Two key characteristics which distinguish CWA from other HF and STS frameworks is its focus on constraints and its formative nature, this is focus lays on determining '*how activities and tasks can be conducted'* within the system (Vicente, 1999; Salmon et al., 2010). The framework is divided in five phases, each focused on modelling different constraints within the system, ranging from environmental constraints (physical, technological, cultural and organisational) in which the system embeds, to constraints derived from the user's cognitive capabilities and preferences.

Although the framework was developed in the 70s and 80s, its application became common in the 90s, mostly through Ecological Interface Design developments (Vicente, 1999). Ever since, the toolkit has been applied to multiple contexts, including urban planning and infrastructure design (Stanton et al., 2012; Read et al., 2015; Stevens and Salmon, 2016; Read et al., 2017). Recent applications of the framework have intended to inform the design of complex infrastructure systems (Read et al., 2016), such as railway crossings, or the assessment and design of complex urban systems, such as cities and high-streets (Beevers et al., 2016; Stevens, 2016; Patorniti et al., 2017; McClymont et al., 2018; Patorniti et al., 2019). Some of these domains, especially those related to urban planning, resemble challenges similar to the ones faced by HEI, particularly in regard to campus developments. However, up to date CWA, nor other STS approaches, have been explored to aid on the design and evaluation of campus learning spaces or facilities from an architectural standpoint. The later sections investigate the university and the campus as complex systems, and discuss potential ways in which CWA, particularly based on its latest advances aimed to the design of complex infrastructure system, (Read et al., 2014; Patorniti et al., 2019) could be applied to complement learning space and facilities design and evaluation processes.

Complexity in Higher Education Institutions

As previously addressed, in regard to new developments learning spaces, facilities, the complex interrelations between technologies, pedagogic practices, spaces and users, have started to be acknowledged within recent design and evaluation initiatives (Radcliffe et al., 2008; Pearshouse et al., 2009; Brown et al., 2017). Although these perspectives point towards an initial shift towards non-deterministic paradigms of research, system's thinking and approaches are still rarely featured. For this, a first necessary step involves the exploration of how does a HEI characteristics relate to those in STS and complex adaptive systems. Herrmann et al. (2004), suggested the consideration of the university as a STS, based on how learning environments are supported by ICT through facilitation of collaborative and organisational processes. This perspective refers to ICT infrastructure, while physical campus and its components, such as buildings, civil and natural infrastructure remained overlooked. As seen in table 3, HEIs possess different

STS features, ranking particularly high in social ones, while technological ones are featured but often result in lower degrees, although the later still comprises challenges.

[Insert Table 3 within this section].

A new approach for the evaluation and design of HE learning environments

The review of recent developments in learning space design and evaluations, particularly those in HE, showcased the need for new methodological approaches that can shed light into the complex interrelationships occurring in the interface between the spaces, technology and the pedagogic activities. The degree of complexity in which HEIs operate is showcased by exploring the context in which universities operate, which can be characterised as that found in complex STS (Table 3). STS approaches encourage a shift away from deterministic and reductionist views that have dominated user-related evaluations of the built environment (Vischer, 2008; Watson et al., 2016). Encouraging an approach that integrates the perspective of multiple stakeholders, at multiple levels within the institution. STS interventions do not only concern with the technical solution but offer a chance to rethink the way in which work practices, organisational and cultural aspects, interconnect with technological ones, such as buildings, learning technologies and the ICT infrastructure.

The synergy of HF methods, and CWA in particular, with well-established architectural design processes, such as the RIBA plan of works (2013), present challenges ahead as far as translating inputs and findings from CWA, a formative approach to systems design, into architectural designs beyond sheer analytical value. However, several previous CWA applications showcase promising synergies with learning space design processes (Figure 1). The following sections provides an overview about the proposed interventions.

[Insert Figure 1 around here]

CWA Intervention 1: Post occupancy evaluation and design requirements

As seen in Table 1, most dominant POE approaches in HE rely on occupant satisfaction questionnaires, and at a lower extent on qualitative methods (primarily focus groups). Questionnaires shine, as a diagnostic tool, as they reveal issues with user dissatisfaction with different building services (heating, cooling, ventilation…) in an inexpensive manner. Qualitative methods, topics in discussions remain similar to surveys, however, they have the potential to reveal other underlying issues, however, data collection and analysis are costly and time consuming. As seen in table 1, the outcomes from these studies are descriptive and summative in nature, with some potential to feed into design briefs through a set of normative recommendations.

CWA offers a theoretically sound framework, based on ecological perception theory (also known as theory of affordances) and naturalistic decision-making, that guides and structures data collection and analysis. The systems approach offers broader insights into user's behaviours, activities, decision-making processes and the broader aspects of the institutional environment. This avoids focusing solely on the built solution and enables a holistic view of the interactions between organisational structures (strategic purposes, roles, ethos…) and physical objects and technologies. This offers the possibility to develop comprehensive organisational and technical requirements for campus developments, thus improving the outcomes of the briefing process. The toolkit offers formative insights, this is, enables to explore consequences and impact of system changes, such as the implementation of new technologies. Furthermore, CWA is a flexible toolkit, enabling to understand the characteristics and singularities of the different HE institutional contexts.

However, CWA is often considered a complex toolkit, which requires understanding and iterative analysis to model the system. Furthermore, translating CWA findings and insights, into outcomes and design solutions is considered a challenging task (Naikar, 2013), therefore, requiring an experienced design team to translate these requirements into designs. This might result hinder the adoption of this approach, particularly when comparing it with the relatively inexpensive dominant occupant satisfaction surveys.

CWA Intervention 2: Pre-occupancy evaluation of design concepts

A major limitation identified in POE (Table 1) is that the majority of the approaches are applied once the building is in-use, commonly a year into occupancy. While this is a logical as to obtain valid occupancy data, the outcomes of these studies often only result in finetuning adjustments of building systems. This issue is highlighted by Lee and Tan (2011), who indicate the need of evaluations early in the design process. Furthermore, the assessment methods that are often applied to asses design concepts are reliant on expert's opinion (DQI and LSRS).

The proposed CWA Pre-Occupancy Evaluation (PreOE) intervention consists on evaluating and appraising different design options in order to understand the impact that those designs, including the technological features, have on the system's high-level purposes and criteria. Recent applications that resembling this approach have only used the model developed in the first phase of CWA, Work Domain Analysis via use of the Abstraction Hierarchy (Stevens & Salmon, 2015; Beevers et al., 2016; Patorniti et al., 2017; McClymont et al., 2018). Some of these approaches use objective metrics (e.g. network metrics and social network analysis representations), to assess the impacts of systemic changes on the overall functioning, which would overcome the reliance on expert opinions of available POE approaches. In the design of a learning spaces, CWA-PreOE has the potential to evaluate how different spatial designs and the features integrated within them, once early design concepts and documentation have been developed, comparatively support or hinder higher level organisational functions and purposes.

The development of the model remains a major limitation for the adoption of CWA-PreOE, as developing an Abstraction Hierarchy still remains challenging, requiring a skilful analyst. However, the fact that only the first phase of CWA, Work Domain Analysis, is commonly applied, reduces the relative complexity of the toolkit, particularly when compared with the previously described CWA-POE intervention. Another limitation is the lack of a standardised approach to conduct these concept evaluations. The studies using network metrics are still at an early development stage (Beevers et al., 2016; McClymont et al., 2018; Patorniti et al., 2019), and therefore further research is required to ensure the validity of the system's performance assessment.

CWA Intervention 3: CWA- Design Toolkit applied to building design processes

CWA-Design Toolkit (CWA-DT) is a recent expansion of the toolkit, focused on bridging the gap between the analysis and the development of design concepts underpinned by STS principles, a frequent challenge faced by HF practitioners (Read et al., 2015; Read et al, 2016; Goode et al., 2016). The toolkit includes different design tools to translate the analysis insights and findings, for instance, use of personas, assumption crushing, situations, events, leverage points, scenarios or sociotechnical principles. CWA-DT uses have been featured in a series of participatory design workshops, which involved relevant stakeholders and end-users. The workshops included idea/concept generation and concept evaluation and selection workshops. Based on these workshops, findings and insights from CWA have been considered useful to translate HF requirements into designs (Read et al., 2018).

Participatory design processes are not unknown to the architectural design process, mostly in hospital design. The challenge is bridging the gap between users and facilitating their involvement into designs of spaces (e.g. mock ups, use of plans, priorities or user testing), which requires of a skilful facilitator. A possible stage in which CWA-DT could be used within architectural process is the value studies taking place when early designs and concepts are being developed, for example, during design charrettes and workshops with stakeholders and users.

Discussion and conclusions

With UK's HE current levels of capital investments on estates, the retrofit of existing estates through technology-enhanced, informal and social learning initiatives offer significant opportunities for the application of STS methodologies, such as CWA. These investments include both formal learning facilities (classrooms, lecture theatres tutorial or seminar rooms), informal learning facilities (library spaces, learning commons or social learning spaces) and other recreational ones (like sport facilities, religious facilities, restaurants or cafés). Most of these spaces were developed with the principles of didactic-learning behavioural models and efficiency/capacity as criteria. However, new technologies and the prioritisation of socio-constructivist learning and its principles (self-directed, collaborative, active learning, problem-solving etc.), provide a new landscape of opportunities to explore new and innovative designs that acknowledge the role and impact that design can have on learning and its associated cognitive processes. It is in this complex context, where STS and CWA provide an opportunity to explore new designs, based on an understanding of systemic constraints, of the environment, institutional cultures, ethos and structure, the pedagogic activities and the constraints underlying user's competences and preferences. Campus development and management are complex sociotechnical matters, which involve the views of multiple stakeholder, sometimes conflicting between each other. A systems analysis offers opportunities to understand ways in which new developments can impact the overall functioning of the system, in this case the university and its campus, while integrating the views of relevant stakeholders and perspectives. Including, amid others, from estates and facilities managers, learning technologists, academic developers, or information services. Thus, complementing recent approaches focused on understanding end-user learning experiences and micro-interactions, including those in the context of designing successful learning environments such as courses, academic libraries or museums (Shapiro et al., 2017; Johnson and Khoo, 2018).

The paper set out to provide answers to the current limitations in learning space design and evaluation showcased by research (Temple, 2008; Lee and Tan, 2011; Cleveland and Fischer, 2014). It has been argued that amid other disciplines, HF methods, especially those concerned with the analysis of complex sociotechnical systems offer relevant tools to explore inherent complexities in the interaction between space, learner, technology and pedagogic activities. CWA in particular, as a formative approach, provides the means to explore the impact of new designs and learning-technologies, not only in its immediate surroundings but in relation to HEI's structure and ethos.

This paper offers new perspectives to address the inherent complexity within learning spaces and campus developments, and some of the shortcomings of dominant space design approaches, through three distinct interventions. These interventions have been laid out using UK's prevailing architectural design process, RIBA PoW (2013), while providing an overview on how they can complement existing design and management processes. For HF practitioners, we hope the paper expands the practice to new domains in which design methods for complex STS, such as CWA, have a promising role in complementing current design and management practices. Within the built environment, other relevant domains in which CWA could prove valuable include, healthcare facilities, major infrastructure hubs or urban developments. The current paper's aim is exploratory and conceptual, serving as the basis for future research by providing a discussion on how the application of STS theory and analytical methods such as CWA, complement current limitations highlighted in higher education space design and evaluation. Ongoing research aims to analyse and model a HEI at different levels, at a campus, building and space level, thus, providing the opportunity to examine the utility of the proposed interventions.

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Table 1 POE approaches in HE

POE Approaches	Data Collection Methods	What they Measure/Evaluate?	Strengths of the Method	Shortcomings	Stage RIBA PoW	References
Occupant Satisfaction Surveys: E.g. Building in Use Survey (BUS) or the Overall Liking Score	Survey Questionnaires (commonly involving around 40-50 questions) Can be complemented by focus groups and walkthroughs.	Occupant satisfaction with different features, and functional and technical aspects of the building. They also measure user's perceived productivity.	Relatively easy and quick usage of a pre-defined questionnaire. Possible to benchmark with other cases. Summative/Descriptive tool.	Mostly a diagnostic tool. Focus on identifying issues, not necessarily on providing solutions.	Stage 7: In use	Leaman and Bordass (2001); HEFCE (2006)
Design Quality Indicators (DQI)	Questionnaire survey	Satisfaction with and perceived quality of the built solution on three dimensions Aesthetics, Functionality and Impact?	Relatively easy and quick usage of a pre-defined questionnaire. Possible to benchmark with other cases. Summative/Descriptive tool.	A tool to assess the perceived quality of a design/built solution from the perspective of different stakeholders. Can serve as the basis to further discussion.	Stage 1 & 2: Project brief and Concept Design Stage 7: In use	HEFCE (2006); Gann et al., (2003)

Post-occupancy Review Of Buildings and their Engineering (PROBE)	BUS questionnaire, Walkthrough and Energy Performance Assessment	Occupant Satisfaction and Perceived Productivity Building Systems Performance Assessment (Energy Performance)	Well defined process (BUS + Energy assessment). Possible to benchmark with other cases. A good tool to fine-tune (energy and building system's) performance of a building. Summative/Descriptive tool.	Mostly a diagnostic tool. Focus on identifying issues, not a formative tool.	Stage 7: In use	Bordass et al. (2001)
Soft Landings	Offers a management and collaboration framework. Methods include workshops and forum meetings. It can be complemented by occupant surveys, and energy/environmental performance reviews.	Focus on reviewing the project process and increasing collaboration among stakeholders - Involvement of Facility management at early stages. And involvement of contractor, designer during handover and early commissioning. Focus on	Flexible tool requires a good facilitator. Possibility to improve communication and collaboration within the project team. Smoothens the handover process and potentially reduces costs on reworks and fine-tuning of building systems.	Lack of guidance and requirement of stakeholder engagement and a good Soft Landings facilitator. Often focus on troubleshooting/incremental improvements on performance. Cost increase for commissioning architect and builder post-occupancy	Different points, but primarily applied in: Stage 1: Project brief Stage 6: Handover Stage 7: In use	BRSIA (2009); Way and Bordass (2005)

		building systems performance issues.		(generally not included in traditional projects)		
UseTool	Focus Groups, Walkthrough and Workshops with users.	Assessment of building's usability for the users and organisation. Review of tasks and issues found by users on the context they occur.	Flexible tool, which enables context dependent findings. It enables users to raise various concerns. Can provide good insights on the alignment of user needs with the built solution.	Lack of guidance on its application. Requires good facilitators. Largely descriptive findings.	Stage 7: In use	Hansen et al. (2011)
Learning Space Rating System	Project Documentation Review and Expert Evaluation. Assessed against credits (LEED/BREAM style)	Assessment of potential performance of a learning space, particularly in regard to promoting active learning pedagogies. Includes assessment of the institutional alignment, process review, and the design solution, including	Pre-defined assessment toolkit, including requirements for credits. Possible to benchmark scores across cases. Summative tool.	Tool developed to assess Active Learning Teaching spaces. Other space types are not necessarily covered. What supporting evidence is required is not clear. Relies on expert evaluation. Tool in early development stages.	Stage 2: Concept Design Can also be used in: Stage 7: In use	Brown et al. (2017)

		fixtures, systems and technologies.				
Building Research Establishment's – Design Quality Method (BRE-DQM)	Expert Observation and Judgement, User Questionnaire, Environmental Measures	Design Quality and Building Performance, around 6 areas, measured via matrixes - Architecture, Environmental Engineering, Whole Lifecycle costing, User comfort, Detailed design and User Satisfaction	Comprehensive review of design quality, covering all aspects of building systems. Offers a summative assessment of building performance and design quality.	Complex and time-consuming methodology, which relies on expert judgement. Does not focus on activities, nor technologies.	Primarily in: Stage 7: In use Can also be used in: Stage 2 & 3: Concept and Detailed design	Cook (2008)

Table 2 Review of recent learning space evaluation and design initiatives in HEIs

Study Details	**Findings on learning space design and evaluation approaches**
In Sync: Environmental behaviour research and the design of learning spaces (Scott-Webber, 2004)	Based on a review of environment-behaviour research, Scott-Webber (2004) a set of visual archetypal spatial designs and principles to design environments suitable to support behaviours, for knowledge-sharing activities in adult learning environments (corporate and academic). Beckers et al. (2015) offer an adaptation of these archetypes of spaces specific to universities, drawing also from findings from theories of pedagogy and learning.
Learning spaces (Oblinguer, 2005)	The collection includes approaches on how the effectiveness of existing and developed HE spaces can be assessed, through understanding interactions between the physical spaces, the students' outcomes, and pedagogic practices. The assessment presented acknowledges the complexity of interrelating those three variables by proposing a multifactor/multi-method framework: combining quantitative surveys, benchmarked against a university wide engagement survey, focus groups and periodical observations via photographic evidence.
Guide to Post Occupancy Evaluation – (HEFCE, 2006; Riley et al., 2015)	It offers a comprehensive "pick and mix" type toolkit of methods, from traditional POE approaches such as, questionnaires, Focus Groups and Walkthroughs. It also provides guidelines for conducting POE, including suggested timelines to undertake evaluations linked to its purpose. After 10 years of use, the model was perceived as a complex toolkit that failed to adapt to the context of each institution. The model has failed to achieve widespread adoption across industry.
Learning Spaces in HE - Radcliffe et al. (2008)	The researchers propose a model to facilitate the design, evaluation and operation of learning spaces by emphasising the relationships between pedagogic practices, space and technology (PST), through the use of guiding questions for design and in-use

	studies. The compendium encompasses a wide variety of case-studies, showcasing different methods and techniques for evaluation.
A study of effective evaluation models and practices for technology supported physical learning spaces - Pearshouse et al. (2009)	The report showcased the predominance as evaluations of questionnaires and focus groups within UK universities, undertaken mostly as one-off processes. Only a small sample of the institutions shared evaluation results through reports or papers. Most sharing occurred informally through visits to fellow universities. Bligh and Pearshouse (2011) later presented a taxonomy of evaluation models based on the values they aim to assess, these taxonomy offers insights into evaluators' assumptions: - **Demand**: Traditional evaluations of space efficiency (cost per sqm, FTS per sqm...), common in Estates Management. - **Outcome-Based**: Based on quasi-experimental approaches, aiming to assess how space affects learning outcomes. - **Satisfaction Model**: A simplified subtype of outcomes model, these approaches assess user's satisfaction or experiences of space use. - **Design-Scenario**: Approaches aiming to predict behaviours that will occur in the spaces. Once spaces are developed, activities are observed and assessed against those predicted scenarios. - **Activity-Based**: Assessment types consisting of observation studies without predefined assumptions, including ethnographic studies. - **Spatial Ecology**: Holistic evaluations of campuses, studying relationships and synergies between multiple spaces.
A comprehensive learning space evaluation model - Lee and Tan (2011)	The study commissioned by the Australian Learning and Teaching Council showcased a number of challenges faced by evaluations of learning spaces, such as: - Lack of resources for comprehensive evaluation, conducted by individuals as extra workload.

	- A market pressure which seeks successful projects and claims of positive contributions. Spaces are presented positively and de-contextualised, offering few opportunities for learning. - Limited understanding of the purpose of evaluation, especially in its role as a design tool in the form of design inputs is underappreciated. - Limiting assumptions about potential for design inputs from the stakeholders that are closer to the usage of facilities. - The complex nature of evaluations themselves, which require flexibility to adapt to different constrains and needs faced by institutions.

Table 3 Characteristics of STS and implications for HEIs (STS characteristics adapted from Vicente, 1999; Carayon, 2006)

Sociotechnical characteristics	**Description**	**Examples within university campus design and management**	**Degree of Prevalence**
Large problem space	Many different elements and forces within the system	HEIs host many academic disciplines; each with their own programmes, courses, research resources. The planning of support infrastructure needs to account for the different interests, space and information requirements.	High
Social	Complex STS include multiple users and employees, who must interact with each other to attain shared goals and a proper functioning of the system.	Student and staff numbers range in size across institutions and across time, however, they frequently surpass the 00s. In 2009, UK student numbers ranged between the 40,000 at Manchester University to the 4,500 at Abertay Dundee University. (AUDE, 2017)	High
Heterogeneous Perspectives	Workers in STS frequently come from different backgrounds which often lead to multiple perspectives and interests, in many cases even conflicting ones.	HEI are compounded of multiple stakeholder groups, including but not only, students, academic staff, researchers, professional services, clerical staff etc. Infrastructure interventions and changes favouring some of those groups might conflict with others.	High

Distributed	Workers and users are located in different geographic locations.	Although not all HEIs are geographically distributed, frequently, universities offer forms of distance education through virtual environments. The implementation of international branch campuses is also a common model in UK, USA and Australia. (Escriva-Beltrán et al., 2019)	Medium - High
Dynamic	Complex systems are usually dynamic and can have long time constants. Effects of actions might be delayed, users have to anticipate the future state of the system and act in advance.	Campus investment and development decisions include predicting trends, demographics, user requirements and potential future scenarios to ensure that facilities and infrastructure remain fit for purpose and future-proof (Den Heijer, 2011).	High
Potential High Hazards	System failures can cause large consequences – e.g. economic, social or environmental.	HEI are safe systems in relation to user's safety and ecological catastrophes. However, their influence in local, regional and even national economy is critical (Den Heijer, 2011). In the UK, HEIs, directly and indirectly, contribute an estimated 52.9b GBP (around 3% of the GDP) and 944,000 jobs to its economy (Universities UK, 2017).	Medium
Many coupled Sub-Systems	Complex STS tend to be composed by many sub-systems	Universities can be divided in many interlinked sociotechnical sub-systems. Professional services, academic departments, research	High

	interacting with each other. This results in difficulties to identify exact effects of actions or tracing back single causes of existing problems.	groups, centres, institutes, and even temporary communities such as those formed by yearly academic programmes, each with distinct users and characteristics (Herrmann et al., 2004).	
Automation	Highly automated systems, controlled by computer algorithms, workers' role is to monitor the correct function and solve problems, when issues occur.	HEIs feature an increasing degree of automation in space management, timetabling, or information resource management. Examples include, learning analytics, adaptive learning technologies or artificial intelligence (Becker et al., 2018) Specialised areas such as research labs and computer labs often feature automated components.	Low - Medium
Uncertain Data	There is a degree of uncertainty in the data available to users/workers	Universities often rely on estimations of student numbers for long-term investment decision-making. In the shorter-term, fluctuations in student numbers per course might occur, in turn, affecting timetabling and space allocations.	Medium – Low
Mediated Interaction	Goal-oriented properties are not always directly observable, workers need to process information to	Universities goal-oriented properties involve the need of complex indicators to measure its performance, affecting amid others campus management. E.g. balancing student experience, costs, sustainability goals, productivity, use efficiency etc. (Den Heijer, 2011)	High

	understand these properties.	This has resulted in the need of industry-wide indicators and cross-institutional collaborations. For instance, '*Space Management Report'* in the UK (AUDE, 2017) or '*Planning Survey'* in the US.	
Disturbances	Unanticipated events occur, and workers need dealing with them. Adaptation of work practices to solve issues is often necessary.	Unanticipated situations in campus planning include: - Student requests and complaints - Changes in student demands and expectations - Failures in built-systems and virtual environments	Medium - Low

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