The Virtual and the Physical

Between the representation of space and the making of space

A. Benjamin Spaeth
Wassim Jabi

Architectural space quality, from virtual to physical

Aida Siala[1], Najla Allani[2], Gilles Halin[3], Mohamed Bouattour[4]
[1]MMRCA ENAU, Tunisia & MAP/CRAI ENSA Nancy, France [2,4]MMRCA ENAU, Tunisia [3]MAP/CRAI ENSA Nancy, France
[1,3]{siala|halin}@crai.archi.fr [2]najla.allani@gmail.com
[4]med.bouattour@hotmail.fr

The adoption of digital design has offered new computational methods improving and deepening the morphological dimension of architectural production. Algorithmic and parametric design associated with new fabrication technologies have made generating increasingly complex shapes possible, forming the basis of non-standard architecture. Such approaches raise many interesting questions like the qualitative and functional dimensions of the provided architectural spaces, which remains a very fiercely debated topic in the field of CAAD. This paper looks for the qualitative and functional spatial requirements that ought to be taken into account in these practices to accompany the quantitative data on which models are currently founded, thus providing the possibility of a more complete vision of new space, recognising that space is perceived is a reading of many factors, both measurable and un-measurable.

Keywords: *BIM, Architectural space, Requirements, Spatial quality, Topology*

INTRODUCTION

The continuous development of digital design tools has been concentrated in recent years, especially on the morphological side of architectural production, leaving the functional and qualitative aspects of provided spaces barely explored. Architectural production is based on spatial requirements determined at an early stage of the design process. These requirements are given in the form of geometrical constraints (e.g. length, width, ceiling height, etc.), but also and mainly in the form of non-geometrical ones (e.g. ambiance, accessibility, relation between spaces, visibility, communication, etc.). Current BIM practices do not take those non-geometrical spatial requirements into consideration since they are based on the use of measured standards and codifications, which transform all building information into quantitative data. Thus, only constructive information is taken into account during the design phases (Siala and al. 2016). The qualitative and functional dimensions of architecture, on which the whole design depends in most cases, are not considered. The main question which therefore arises is how exactly to take into account and represent information about spaces within BIM tools. This concerns information on the scale of the space itself as an empty, invisible and immaterial building entity. It also concerns information on the scale of the properties of space, especially non-geometrical ones, like qualitative and topological (or functional) requirements. Non-geometrical information can ensure the transition of the design model, from a set of design requirements expressed by the future user (owner) of the building (described space) to a finally constructed space (physical space), going through the design phases (virtual space).

In our approach, we discuss the concept of architectural space as a key concept allowing the integration of qualitative and topological spatial requirements in current collaborative practices. If those non-geometrical parameters could influence the evolution of the design model according to the future user's needs, their presence in BIM tools would be crucial. So which are the relevant non-geometrical requirements that should be taken into account and what could be their form of representation in BIM tools? Regarding these matters and based on an investigative and analysing work, we propose identifying and representing relevant non-geometrical requirements necessary to describe spaces during the design phases. This restructuring approach aims to take into account non-geometrical spatial requirements, especially qualitative and topological ones, in current collaborative usages. The overall goal of this study is to enable designers to measure, predict, assess, comprehend and manage the layout of spaces and their quality, respective of new requirements, defined at an early stage of the design process.

In this paper, we first focus on the status of architectural space information in recent research works to identify the need for space representation. Then, we look for the relevant non-geometrical requirements that should be taken into account in current collaborative uses. Afterwards, we try to provide a restructuring approach for the identified requirements to allow for their integration and management in current BIM tools as spatial parameters. By the end of this paper, our space model inclusive of relevant qualitative and topological spatial requirements will be demonstrated. A discussion dealing with our future work will explain how to guide current digital design tools towards the qualitative and functional dimensions of architecture.

INFORMATION ABOUT SPACES IN RECENT RESEARCH WORKS

When performing design tasks, architects give space not only a form (geometrical properties), but also a sense (non-geometrical information like ambiance, quality, relation between spaces, etc). Based on a requested program, they provide design models that tend to satisfy the future user requirements. User requirements are usually given in terms of spatial quality and topology (e.g. the intentions required by a house owner might be "*The living room has to enjoy a maximum of sunshine with visibility on the garden. It must be close to the bathroom and communicating directly with the kitchen*"). To identify how space is described in recent research works, several works dealing with space data modelling have been investigated. Between the investigated models, we emphasise the following:

- The IFC model [1]
- KIM model (KIM 2015)
- Ekholm model (Ekholm 2000)
- Bjork model (Bjork 1992)

Based on this analysis work, we noticed that most of the investigated space models focus on the quantitative properties of spaces (e.g. geometric properties, position, quantity, etc. IFC, Ekholm and Bjork models include partial descriptions of topology of spaces, since they allow a space to be decomposed into sub-spaces and admit that a space can belong to a larger spatial structure (zone, floor, etc.). However, none of the analysed models dealt with the possible topological requirements on a space. Proposing a method for automatic updates of spatial requirements, Kim focuses especially on quantitative ones (geometrical requirements, quantity requirements, etc.). Between all the observed works, only the IFC model includes an aspect of qualitative spatial requirements (e.g. whether the space requires artificial lighting, whether an external view is desirable, the activity type of the space, etc). All the remaining qualitative spatial requirements possible are not supported by all investigated models. Qualitative spatial requirements consist of descriptions about the intended whole ambiance of a space (e.g. acoustic, thermal, hygrometric, lighting, safety and coating requirements).

IDENTIFICATION OF SPATIAL REQUIREMENTS

Our purpose in this section is not only to illustrate the different requirement types on a space, but also to discern relevant ones to integrate into current BIM usages. Our method is based on the content analysis of written descriptions of design requirements. This analysis work was organised around three chronological phases, as structured by Wanlin (Wanlin 2007), the pre-analysis work, the tools exploitation, as well as the results treatment, inference and interpretations.

The pre-analysis work

The preliminary work concerns the first phase of intuition and organisation in order to operationalise and systematise the initial ideas to arrive at an analysis schema. To represent the possible concepts describing requirements on spaces, we focused on architectural programming studies developed by specialised agencies in architectural programming. From the available and accessible ones, those having the most detailed descriptions of spatial requirements were privileged. To collect the maximum amount of data, we selected several representative types of real public construction works. Among investigated public works, we emphasise the following:

- The schooler and extracurricular group of Vany, Fance (2013)
- The elementary school of Saint Antonin, France (2016)
- Elsa Triolet College of Thaon Les Vosges, France (2017)
- The emergency Center of Dieulouard, France (2013)
- The nursery and parental care center of Laxou, France (2015)
- The multidisciplinary health center of Montchanin, France (2015)

In the first empirical step, we started by acquainting ourselves with the collected documents. This allowed us to limit the investigation scope letting impressions and certain orientations come about during the reading and re-reading of each programming study. Spatial requirements are described in explanatory texts, tables and diagrams. We proceeded by gathering the close or similar words (lexical words) used to qualify spatial requirements and joining them with their relating descriptions. The identified words and descriptions have constituted the basis of the second analysis step.

This study focuses only on objective spatial requirements, which have factual referents. Requirements like 'pleasant space,' 'cheerful space,' and 'warm space' are completely subjective requirements and cannot be considered in this study.

Table 1
Example of
Accessibility
Requirements
Categorisation

Title	Heading	Word
Accessibility	Access	Access
		Accessible
		Accessibility
	Entrance	Entrance
		Entry
		Entree
	Exit	Exit

The hardware operation

This second phase consists mainly in carrying out the coding, counting or enumeration operations according to the specifications previously formulated. It involves in turn two steps:

The first step concern the categorisation operations, in which we elaborated a grid of categories, is the first step. We started associating each identified word used to qualify a space with the related adjectives. For example, the word lighting was associated with natural or artificial, direct or indirect, zenithal, controlled, etc. Then, words belonging to the same family (having a common cardinal) were grouped under a generic heading. For example, the words *Access*, *Accessible*, *Accessibility*, etc. were grouped

TOPOLOGICAL REQUIREMENTS				
Title	**Heading**	**Frequency**	**Description**	**Frequency**
Relation	Relationship, Connection Pathways, Traffic, Distribution, Communication, Separation	544	Visual / Physical	51
			Direct/ Indirect	17
			Frequent / Occasional	13
			Horizontal / Vertical	12
			Main / Secondary	10
			Clean / dirty	4
Accessibility	Access, Entrance, Exit	499	Principal / Secondary	114
			Access constraints	103
			Interior / Exterior	72
			From / To	69
			For	43
			Direct / Indirect	21
			Easy	19
			Private / Public	13
			Close to / far from	7
			Secure	6
Arrangement	Arrangement, layout	380	Close to, next to, near	151
			A part of, a corner of	28
			Contiguous	8
			comprises	3

Table 2
Topological requirements condensed grid of categories

under the generic heading *Access* (table 1). Next, headings were gathered in turn, by synonyms and/or antonyms under the same title, in order to provide a condensed and simplified representation of the raw data. For example, the headings *Access*, *Entrance*, *exit*, etc. were classified under the title *Accessibility*. Finally, titles were classified by type. For example, titles *Accessibility* and *Relation* and *arrangement* were classified as Topological requirements, where *Accessibility* gathers requirements concerning the access to space and the exits, *Relation* groups requirements about connection between spaces (relationship, pathways, traffic, distribution, communication, separation, etc.) and *arrangement* gathers the adjacency requirements (proximity, layout, etc.).

This step has allowed us to identify and apprehend the different types of spatial requirements. Illustrated spatial requirements are classified into five types, namely: **geometrical requirements** (shape and dimensions), **quantity requirements**, **occupancy requirements** (Equipment, number of occupants, occupancy duration, activity type, etc.), **topological requirements** and **qualitative requirements**. Among these requirement types, we are primarily concerned with non-geometrical requirements, in particular topological and qualitative ones.

The second step involves filling the grid according to the identified words and their descriptions with the related usage frequency. Software supporting qualitative and combined research methods were used to systematise the coding and counting works (NVivo [2]). The topological anand qualitative requirements condensed grids of categories are shown in Tables 2 and 3.

Interpretation, inference and validation

In this last phase, the raw data is treated using simple statistical operations (based on percentages) to be meaningful. The results are summarised in diagrams (Figure 1) that condense and highlight the information provided by the analysis work. A final step in this analysis work focused on the results verification. Our approach was verified by statistical tests on a new real public work programming study. This verification was carried out on a project that falls within the educational framework since half of the analysed programming studies belongs to educational institution projects. The selected programming study concerns the kindergarten of Jean Jaures, Libourne -France (2012). We noticed in this final step that results were very close and in some cases even statistically identical. It should, however, be noted that slight differences which do not exceed 6% were found in certain descriptions . The verification work has enabled this study to identify new families of words synonymous with those presented in this analysis work.

DISCUSSION

Topological requirements are described in texts, diagrams and functional flow charts, which explain the required arrangement between spaces, the relationship between them and accessibility constraints. Topological descriptions are almost fixed and recurrent in all analysed programming studies. Figure

Table 3
An excerpt from qualitative requirements condensed grid of categories

QUALITATIVE REQUIREMENTS				
Title	**Heading**	**Frequency**	**Description**	**Frequency**
Coating	Coating, peinture	826	Type (marble, tiles, parquet, plinth)	506
			Finish (anti-slip, washable, easy to clean, waterproof, Resistant to friction)	127
			Of (wall, ground, ceiling, ...)	79
			Complies with (standards)	16
			Adapted (Space type)	1
Hygrometric	Hygrometry, Ventilation, Extraction, Air renewal	628	Natural / Mechanical	77
			Reinforced, powerful, ...	52
			Type (nitrogen, oxygen, ...)	39
			Adapted (Space type)	15
			Rate, flow, type, diameter	15
			Day time / Night time, Time, date, season	4
			Complies with (standards)	3
			Primary / secondary	2
Acoustic	Acoustic, Noise, Phonic	611	Complies with (standards)	27
			Adapted (Space type)	16
			Performance (dB)	13
			Reinforced, of quality, ...	9
Thermal	Thermal, Air-conditionning, Heating, refreshment	611	Will/will not be, Air-condionned/ heated	76
			Temperature (°C)	66
			Complies with (standards)	29
			Time, date, season	9
			Required	3
			Efficient	3
			Adapted (Space type)	1

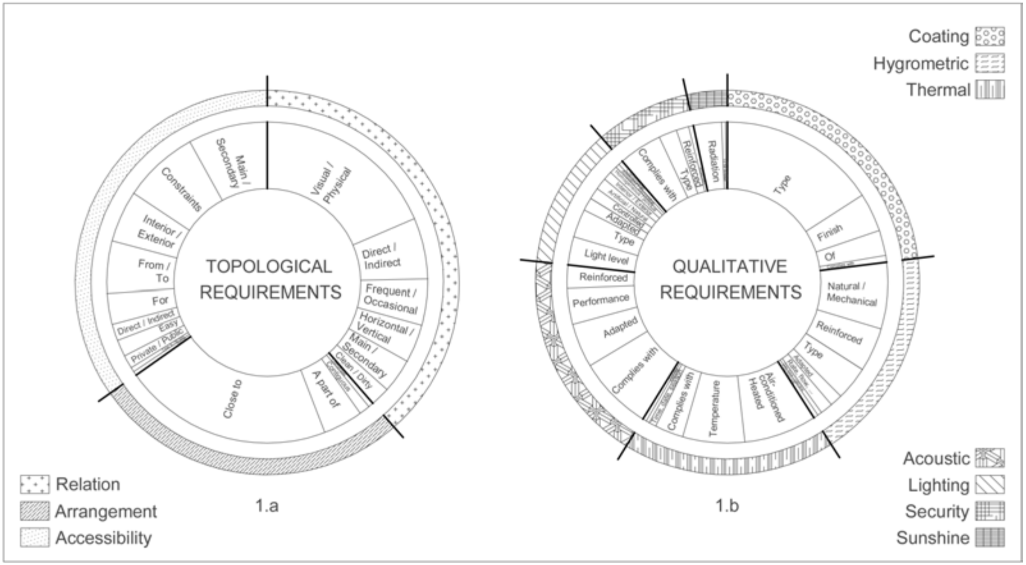

Figure 1
Topological (1-a) and qualitative (1-b) requirements, descriptions and related use frequency.

1.a shows that the must used topological requirements are: the arrangement of spaces (close to, next to, near, etc.), the type of communication relation between spaces (visual or physical), the accessibility type (main or secondary) and constraints (width, height, etc.), the type of connection relation between spaces (direct or indirect), etc.

Figure 1.b shows that much of the qualitative descriptions are indicated to raise awareness about the importance of certain qualitative aspects of space (e.g. air-conditioning, heating, ventilation, noise, etc). For example, 42% of acoustic requirement descriptions revert to existing standards and regulations (complies with, conforms to, standardised, etc.). 25% of these descriptions revert to the space type of the activity type in which they will be housed (an adapted treatment, the attenuation will be adapted accordingly, etc.) and 14% describe the desired acoustic quality (reinforced, optimal, of quality, etc). Only 20% of the acoustic description are quantitative (attenuation: 60 dB, 43 dB, etc). Thus, 80% of the acoustic requirements refer to standards and engineering.

Qualitative requirements gather descriptions that define the overall ambiance of a space. This analytic work has enabled this study to identify qualitative descriptions very commonly used in the programming phase. These descriptions concern: the coating type of a space or space-type (marble, tiles, parquet, etc.), the acoustic attenuation (which must complies with standards), the thermal needs (must be air conditioned, will be heated, etc.), the required ventilation (natural or mechanical), among other things.

It should be noted that qualitative and topological requirements include essentially qualitative descriptions, which are generally given in binary and opposite representations (e.g. interior *exterior, main* secondary, direct *indirect, artificial* natural, etc).

Topological requirements include only qualitative descriptions. Qualitative requirements are more important then topological ones as 71% of the descriptions relate to spatial quality. They include not only qualitative description, but also some quantitative ones (e.g. the required temperature (°C) in a space, the ventilation flow (m3/h), the sound attenuation (dB), the solar radiation (wh/m²), etc) along with other typological descriptions, like types of coatings, spot lights, stores, among others.

All these descriptions are useful during the design phases to assist the design evolution process in taking into account both measurable and non-measurable requirements. To further illustrate our results, the diagrams presented above were summarised in a single diagram (Figure. 2) based only on significant percentages. To descry the relevant descriptions of spatial requirements, we have defined a percentage threshold (10%) below which descriptions were not taken into consideration. Based on this final diagram, the next section consists of the representation of the identified relevant requirements in a space data model.

Figure 2
Topological and qualitative requirements summarised diagram

A SPACE MODEL INCLUDING NON-GEOMETRICAL QUALITATIVE AND TOPOLOGICAL REQUIREMENTS

This section presents our view of how relevant spatial requirements can be accommodated in the same schema and how can they be related to spaces.

In addition to <Geometrical> spatial requirements (area, width, ceiling height, etc.), <quantity> requirements and <Occupancy> requirements, our space model (Figure 3) includes also <Qualitative> and <Topological> requirements as classified in the previous section. Proposed space model consists of two instances: the Requirements Model and the Design Model.

In the Requirements Model, a <Space> should satisfy a set of requirements according to its <Space Type>, <Space SubType>,<Activity type> or <Activity SubType>. For example, in a university, the space "Pedagogical depot-003" should satisfy topological qualitative descriptions imposed by its <space type> as a "Depot" (All depots will have direct access from the common traffic). It should also satisfy those required by its <Space SubType> as a "Pedagogical depot" (Pedagogical depots for the storage of teaching materials must be contiguous to classrooms and accessible directly from them). Thus, the space "Pedagogical depot-001" must satisfy both of those requirements. Its final topological requirements would be as follows: contagious to a classroom, access from the classroom, and access from the common traffic. Thus, requirements with qualitative descriptions are cumulative.

On the other hand, a <Space> should also satisfy a set of requirements according to the <Activity Type> or <Activity SubType>. For the same example of a college, the <SpaceType> "Classroom" should satisfy requirements imposed by its <Activity type> "Having Class" (a natural lighting is required) and those required by its <Activity SubType> "watching projection" that necessitates stores to minimise the natural lighting. The resulting requirements here will be: natural lighting, equipped with stores.

In the Design Model, architectural <Space> has three types of data classified as follows:<General> data, which indicates general properties of space (e.g. ID, GUID, name, etc.).<Geometrical> data, which groups geometrical properties of space (e.g. length, width, ceiling height, position, etc.) and <Quantity>

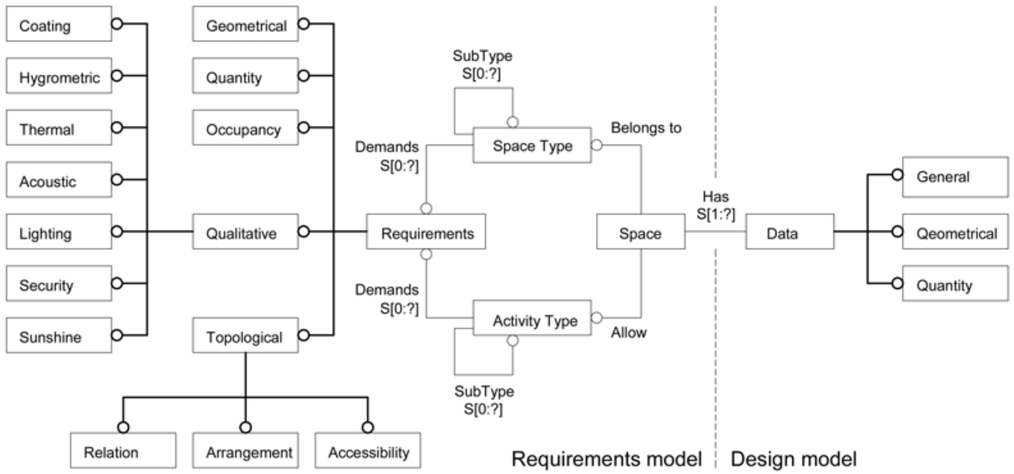

Figure 3
Schema of space data model, including identified qualitative and topological requirements

data, which gives the location of space in the entire model.

CONCLUSION

The overall goal of this research is to assist designers in providing architecture that satisfy non-geometrical requirements described during the programming phase, especially topological and qualitative ones. Those requirements are implicitly known by designers and architects in current collaborative usages, since the absence of qualitative information within BIM models is currently evident.

We have attempted in this paper to provide a structural approach of the relevant topological and qualitative requirements necessary to be taken into consideration in collaborative usages. This approach had allowed us to propose a data modelling all information about spaces, their requirements and properties. A future work will focus on new collaborative usages allowing designers to add and manage topological and qualitative spatial requirements during the design phases.

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Architects' use of tools for low energy building design

Methodological reflections from Ethnography and Philosophy of Technology

Gabriela Zapata-Lancaster[1]
[1] Welsh School of Architecture, Cardiff University
[1] ZapataG@cardiff.ac.uk

Design practitioners face an increased pressure to design low energy buildings because of the need to reduce the carbon emissions of the built environment. As a response, building performance simulation tools (BPS) have been created for designers to facilitate the decision-making and help them to propose low energy buildings. This paper is based on a research that adopted ethnographic research to conduct a case study comparison and explore how BPS tools were deployed by designers during real-time design process. The research adopted a constructivist approach informed by philosophy of technology and human computer interaction theories to reveal what designers were doing during the design process as opposed to what they should be doing according to best practice advice. This paper focuses on the application of ethnographic methods and brings attention to the advantages, challenges and limitations of adopting ethnographic research to investigate the `context of use of tools'. The discussion of the method brings attention to the context of use of tools as the departure point to develop a range of solutions for design support.

Keywords: *building performance simulation, design tool, design process, energy performance, ethnography, social context*

INTRODUCTION

There has been a rapid growth in the number of BPS tools that fit all the stages of the design process (from early to advanced design), to be deployed by different practitioners: architects, building services engineers and energy specialists. While the benefits of using BPS tools in the design process are widely recognised, building designers face several challenges to incorporate BPS tools in the design process (Zapata-Lancaster and Tweed 2016; Alsaadani and Bleil de Souza 2012). The use of BPS tools in routine design process is likely to be limited and their potential impact as design-aid remains latent (Clarke et al., 2008), suggesting a gap in the practical use of BPS tools by designers (Macdonald et al., 2005). Research on performance gaps (discrepancy between the as-designed intentions and the actual building performance during operation) suggest the failure of as-designed performance calculations to represent the performance of the building in use and discrepancies due to different factors (Van Drokenlaar et al 2016). The study of design support tools for practitioners has been carried using questionnaires, interviews and focus groups. Despite the important contributions of those approaches, they are limited in providing an in-depth analysis of the context where designers operate. The context of use is likely to affect the way BPS tools are invoked in the design process, as highlighted by the Zero Carbon Hub (2010): "...performance issues are more much more concerned with the processes and cultures within the industry than with the model that is used to predict carbon emissions". Therefore, the purpose of this ethnographic study was to reveal in detail the context where designers operate and how they inform the low energy building design; including design process aspects, knowledge aspects and tool deployment aspects. The study aimed to investigate in detail how BPS tools were used in the real-time routine design process (do design teams use BPS tools as recommended by best practice advice, as expected by the BPS tool developers ?) and more importantly, why were BPS tools used that way (understanding that can inform the development and improvement of tools, identification of design support needs that could translate into tool improvement and/or the identification of features and capabilities as perceived by the users). This paper discusses the use of ethnographic methods to investigate the 'context of use of BPS tools'. The reflection about the application of ethnographic methods as a way to engage with the users aims to encourage the debate about how the researcher and tool development community engage with the anticipated users to understand their needs and solutions for design support.

LITERATURE REVIEW

Philosophy of technology and human-computer interaction perspectives question tool-centric approaches that reduce human action and problem-solving to deterministic models where the tools fit into processes regardless of the features of the context where they are incorporated. Winograd and Flores (1987) argue that technologies become part of the pre-existing network of human interactions. Therefore, the context should be considered to understand how technologies fit and change the network where they are used (Winograd and Flores, 1987). Conventional ways of thinking that assume that technologies fit as forecasted by the tool developers are likely to be misleading because they neglect the interaction between tool and user in the context of use (Borgman 2004). In this sense, Gibson's concept of affordances is relevant to highlight the potential of an object to enable action (Gibson 1979). Affordances relate to the inherent characteristics of objects, to the ways that users perceive the potential of objects to enable or deter action and the enactment of different sets of actions. Affordances are latent and their realisation requires the 'association of objects and situatedness' (Hodder, 2012). In other words, whilst objects have the potential to facilitate action; the user and the context of use play a role in the ways objects are deployed.

The affordance of objects and the situatedness are part of the relativity of the relations human-technology and culture-technology (Ihde, 2004). While technologies provide a 'framework for action'; they are defined by existing patterns of use, intentions and preferences. Ihde (2004) uses the term 'double ambiguity' to refer to the dichotomy between 'trajectories of development' and the 'instrumental intentionalities' of objects. The trajectories of development are the ways how users use the tool while the instrumental intentionalities are the uses anticipated by tool developers. Ihde argues that the intended uses of tools outlined by their developers have little effect on the subsequent history of the tool because the user can develop a variety of uses including ones that might not have been anticipated by the developers (Ihde, 2004). Idhe's argument does not negate the technical properties of objects; it simply draws attention to the idea that tool's properties are part of relativity of the human-technology relationship.

In architectural and engineering research, a number of precedents have addressed the use of tools from a perspective that acknowledges the human-tool juncture. For instance, Bucciarelli (2002) suggest that artefacts facilitate the communication, negotiation, learning and living the language of engineering. Bucciarelli (2002) argues that tools are part of the construction of common understandings and praxis. Similarly, Berente et al. (2010) point out that new tools are introduced to old systems and routines, leading to new configurations of practice while Coyne et al (2002) use the 'evolutionary metaphor' to highlight the dynamic nature of devices and the complex ecology of devices to refer to notions such as derivation, improvement, survival, suitability to purpose, adaptation, inheritance of features, and recombination. Those arguments suggest that tools are part of complex processes and the relationships they establish as individuals within groups. Tweed (2001) looks at the early introduction of CAD in design practice and suggests that the stereotypical and totalising view that represents the end-user as a single type of designer fails to consider the beliefs, norms, values and history of end-users that fall outside the ideal type. Simplified assumptions about the way practitioners engage in problem-solving may be limited because they are prone to focus on a typical or rational 'ways of doing' that could overlook (tacit) features of practice. This aspect has been addressed by Chastain et al (2002) and Harty (2008). Chastain et al (2002 p.239) suggest that the properties of tools are inferred from the tool developers' assumptions of praxis so when a new technology is adopted, a dysfunctional relationship might emerge between tools and tasks. Tool developers embed assumptions and constraints about the intended users which enable and deter the ways how tools are used (Harty, 2008).

These literatures contest the idea of 'ready-made' tools and suggest that tools are used in relation to their cultural and social dimensions beyond their inherent capabilities. In spite of the artefactual properties of tools, the users are prone to manipulate their properties in use, deploying the tools for purposes other than those anticipated by the tool developer. Tools for low carbon design are in this sense no different to any other tools and could be similarly affected by the social context. The term 'social context' refers to the physical and social location where people interact and develop as part of the group. It comprises the beliefs, paradigms, motivations, attitudes, habits, repeated patterns of action that unfold during the interactions between individuals (Berger and Luckmann 1967). This research acknowledges that the concerns emerging in the design process could influence the potential and perceived affordances of tools, their roles and their patterns of use as compared to what is expected by best practice advice and by models that recommend the 'correct' use of BPS tools by designers.

RESEARCH METHODOLOGY

In order to investigate what people do in real time design process, the study adopted a theoretic framework based on propositions from philosophy of technology and human-computer interaction theories (section above) and develop empirical work using an ethnographic approach. Ethnography is a qualitative research method that enables the study of meanings and experience engendered in the social milieu of a group (Hammersley and Atkinson 1995; Silverman 2005; Bryman 2008). The locus of the ethnographic analysis is culture. It allows the exploration of 'the social issues and the behaviours that are not clearly understood' (Angrosino 2007 p.26) by considering the influence of the social context in the creation of meanings, attitudes and beliefs held by a group (Lecompte and Schensul 1999 p.58).

In design research, ethnography has been used as methodological approach to study practitioners in design and construction; for example, Bucciarelli 1998; Lloyd and Deasley 1998; Baird et al 2000; Ball and Ormerod 2000; Button 2000; Gorse and Emmitt 2007, to cite few. In the ethnographic study about migrant construction workers, Pink et al (2010 p. 658) argue that 'ethnographic research can make visible informal (or unofficial) worlds of action, interactions and ways of knowing that can easily slip under the industry (or official) horizons of notice'.

The study analysed in-depth the design processes of six non-domestic buildings located in England and Wales by four sustainable architecture practices. The study investigated how designers used tools to embed energy performance during routine design process. Building upon the principles of qualitative research (Denzin and Lincoln 1998; 2008; Silverman 2006; Creswell 1998), purposeful sampling was done based on communities of practice criteria . The investigation analysed the conceptual and detailed design phases. The delivery and construction phases were outside the scope. However, the aspects related to delivery, construction and operation were considered in that they overlap to the design process. The main research participants were the architects. Other design team members were included to depict the dynamics and richness of the process.

The ethnography study was conducted for twelve to twenty-one months per case study. It comprised an average of seventy five hours per architecture firm distributed in eighteen to twenty five visits per firm. The data collection methods included interviews, non-participant observation (ie in meetings, design team exercises), document analysis, shadowing of work, visits of construction sites. The performance targets and BREEAM credentials of the case studies are described in table 1.

ETHNOGRAPHIC FINDING RELATED TO BPS TOOL USE DURING THE DESIGN PROCESS

COMPLIANCE V PERFORMANCE-BASED PROCESS

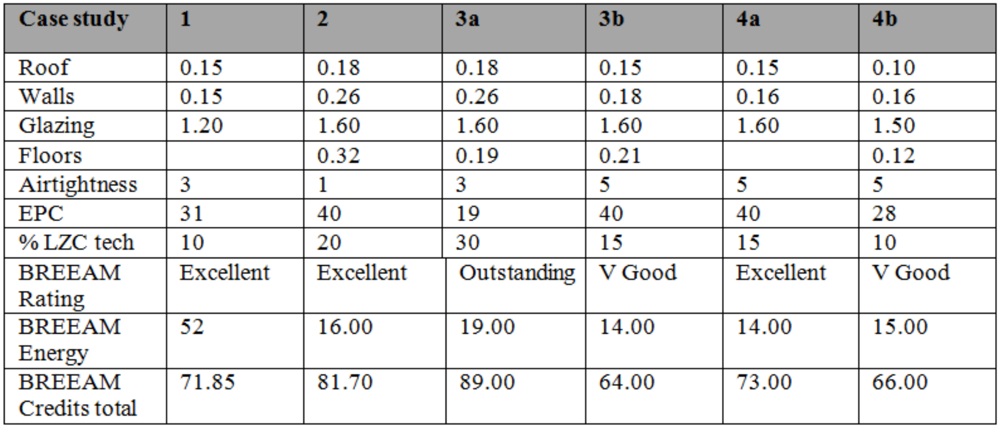
The use of ethnographic research enabled the identification of challenges faced by designers to use BPS tools as recommended by best practice advice (further reading: BSRIA Building Services Research and Information Association 2009. BSRIA BG4. The Softlandings framework for better briefing, design, handover and building performance in-use. Retrieved from http:www.bsria.co.uk/services/design/softlandings/s) . The data suggests that BPS tools were not consistently deployed as recommended by best practice advice. BPS tools were not consistently deployed as expected by BPS tool developers (ie in early design stage, to compare design options, etc) (For further details, see Zapata-Lancaster and Tweed 2016). All of the research participants were working in sustainable architecture firms and designing low energy buildings; yet, the project drivers such as cost, construction time and buildability featured as priorities for decision-making, compromising the energy performance intentions of design teams in some of the case studies. The project drivers of the wider stakeholders (ie. client and construction team) affected the prevalence of the energy target and the use of BPS tools during the design process. As illustrated, by the following quotes, energy performance is unlikely to be an explicit requirement even in low energy buildings:

Building Services Engineer 2: 'the client could not confirm whether cost, quality or time was of most importance'

The client referring to low energy design targets: Client 1: 'if it is not a compulsory requirement, we do not want it'

The ethnographic work enabled the continuous observations of the different ways that BPS tools were invoke in the design process in the context of routine design process. In the case studies (projects designed by architects with experience in sustainability), there were two types of engagement with BPS tools for energy purposes: use of BPS tools prompted by compliance (namely, compliance-only process) and performance-based use of BPS tools (pervasive and consistent use for design decision-making). The level of engagement was observed in the long-term non-participant observation and discussed with the participants during follow-up interviews. The real-time use of BPS tools in relation to the deliverables and the project drivers was a key ethnographic finding that illustrates a facet of the processes and cultures within the building industry.

Table 1
Energy performance targets and BREEAM credentials in the case studies



Case study	1	2	3a	3b	4a	4b
Roof	0.15	0.18	0.18	0.15	0.15	0.10
Walls	0.15	0.26	0.26	0.18	0.16	0.16
Glazing	1.20	1.60	1.60	1.60	1.60	1.50
Floors		0.32	0.19	0.21		0.12
Airtightness	3	1	3	5	5	5
EPC	31	40	19	40	40	28
% LZC tech	10	20	30	15	15	10
BREEAM Rating	Excellent	Excellent	Outstanding	V Good	Excellent	V Good
BREEAM Energy	52	16.00	19.00	14.00	14.00	15.00
BREEAM Credits total	71.85	81.70	89.00	64.00	73.00	66.00

BPS IN COMPLIANCE-ONLY PROCESS-CHALLENGES

The aim of the compliance-only process was mainly to produce as-designed estimation models to demonstrate that the energy regulatory requirements were met. In this situation, BPS tools were invoked only in the light of policy requirements (planning application, building control application) to produce the evidence to estimate the as-designed performance. In that situation, BPS tools were not used to inform the decision making. BPS tools were used fine-tune an already designed building. In the compliance-only circumstance, the use of user friendly design tools was irrelevant because rapid decision making during early design was done on the basis of experience and heuristics (ie rules of thumb, adopting design strategies that were used in previous designs). The main challenges in the use of BPS in the context of compliance only, as perceived by research participants:

1) BPS tools did not afford quick estimation in early design.

2) BPS tools were too time consuming in detailed design to be deployed in parallel to decision making (ie. effort for modelling input and computational time for calculation).

3) BPS tools were perceive as an 'investigation exercise of energy performance' rather than an aid for decision making when the priorities are reducing capital cost and time on site.

BPS, A COMMUNICATION TOOL IN THE PERFORMANCE DIALOGUE

In the performance-based process, BPS tools were used to inform the performance dialogue as recommended by best practice advice. BPS tools and their results were part of the design negotiations and the decision-making throughout the design process. The as-designed estimation informed the design strategies from early design to detailed design.

Interestingly, there was a communication role played by BPS tools to facilitate the dialogue about energy performance within the design team and between the design team members and other stakeholders and decision-makers in the process:

1) Communication within the design team: the energy expert/simulationist conducted the as-designed estimation and took the results to codesign

sessions with other design team members ie. architects, acoustic engineers, architectural technologist in order to decide how different strategies affected different requirements (ie specification of windows in relation to glare, sound protection, heat gains)

2) Communication (education) of the wider stakeholders: the design teams used the as-designed estimations to illustrate the potential benefits of low energy strategies in relation to metrics/aspects that clients were concerned about for example, operational cost. The following excerpt illustrates the BPS use to communicate with the client:

Building Services Engineer 3a: 'They [the clients] wanted to have the PVs on and all those things. They [the clients] wanted to know how much it would save them potentially off their bills because they get just a set budget every year to run and maintain the school, so obviously the more we can reduce the energy consumption, the more they can spend on text books and things like that for the kids.'

This communication aspect with the clients, suggests that the energy metrics obtained by BPS tools are 'translated' to concerns that are more relevant to the stakeholder. For example, the designers in one of the case studies had developed a tool, the energy bill saving estimator. It was a spreadsheet that calculates the weekly costs associated to the energy consumption for space heating, water heating and lighting. The weekly costs were aggregated and compared to the basic income of the user to determine the percentage of basic income likely to be used to pay the energy bills. The clients were more compelled to support low energy strategies if they could link their benefits to potential savings during operation.

3) Communication between the simulationist/energy expert/design teams and the contractor: to link the as-designed performance intentions to actions required from the other team members to facilitate the achievement of as-designed intentions. The BPS results were used to produce evidence about the need of certain performance specifications in building materials and standards on site:

Architect 4b: 'There's a reason why the building is like that, you know. And I think [achieving a low carbon building] it's about educating people. I feel that contractors don't understand what [architects] we've been doing, to the depths that we've taken it. So you have someone, like well, we can do a frame in steel because it's cheaper. Hang on a sec, no, no, the frame isn't just there to support the building, the frame actually has other parts to play in the whole environmental model of what the building is. Yeah, and I think that's shown when we get the questions going, can we use this as an alternative? And you go, well it doesn't work for this reason, that reason and that reason. I can see you want to use it because it looks the same, but that's where the similarity ends. So it's about educating them [the contractors] to really understand ... being more attentive to things like that.'

USERS OF BPS TOOLS

In alignment with Lawson's notion of the designer's problem solving preferences (Lawson 1997) -preference for quick understanding over numbers-, this work found that no architect in any of the case studies used BPS tools or any quantifiable method to estimate performance. User friendly 'early design' tools were not used to inform decision making:

Architect: 'It's about basic principles; do you need software to tell you that?'

Even the Building Services Engineers acknowledged using experience and heuristics for early decision-making:

Building Services Engineer: 'We sort of start talking about the low carbon strategies quite early with them without any calculation so it is quite experience-based in a way. We look at the orientation, the form, the massing, the things that you could do without the calculations, the things that you know that will work. It is done in that way, it is more qualitative than quantitative...'

Another interesting aspect is that the estimation of energy performance was perceived to be a duty for the energy specialist. Generally, there was an energy specialist or simulationist in the design team who deployed BPS tools as requested (either only for compliance or throughout the design process for decision-making). Even within the building services engineering field, it was suggested that the increasingly ambitious energy goals required by legislation were leading to the creation of a 'sub-expertise' in BPS tools:

Building Services Engineer 2: 'Even in our discipline [building services engineering], there is sub-expertise with people who can produce models and worry about Part L and the other engineers who have not been trained in producing models who will rely on the modelling group...'

These aspects bring attention as to whether the move towards the widespread use of BPS tools by practitioners is bringing to question the knowledge and expertise of different practitioners within the design team . (further reference, see Dreyfus (2004)

AS-DESIGNED PERFORMANCE ESTIMATION BY BPS TOOLS AFTER DESIGN PHASE

There were mixed views about the extent to what the results of BPS tools represented the performance of future buildings. There was a generalised concern among research participants that the as-designed estimations did not reflect the in-use performance and that there were connections between the as-designed estimation and the building performance in further stages of the building lifecycle process (construction -as-built performance; operation -in-use performance). This resulted in conflicting views where the designers perceived that BPS tools were theoretical or compliance-only instruments. The as-designed performance estimation was regarded as an uncertain representation of performance unlikely to be met during construction and operation. In other words, the BPS tools were seen as limited for the appraisal of performance due to the uncertainty embedded in the as-designed evaluation in relation to as-built and in-use performance.

Architect 2: 'How reliable is the use of advanced simulation tools?'

Architect 4b: 'You'll never reach the [energy] target; it's some kind of false target really. It's uncontrollable, because you can't control people. You can control lights to a degree; you can obviously control heating and ventilation. But on the modeling we've managed to reach the target and that's completely right if no one is going to switch a plug.'

Building Services Engineer 2: 'Sometimes I strongly disagree with simulation and its pretty pictures... is this helping to understand or just generating pretty pictures, images of performance that can't be mapped against actual energy use?'

REFLECTION OF THE METHOD

The discussion few of the ethnographic findings of the main study presented in the previous section reveals the challenges in adopting BPS tools in the relation to the context of use ie. project drivers (reducing cost more important than energy performance during operation). In situations where energy performance was not an explicit project requirement, the designers could use BPS tools for compliance-only purpose (no/minimum use of BPS tools to inform decision-making) or to support the performance dialogue between stakeholders (using BPS tools to communicate within the design team and beyond). The ethnographic research enabled to identify some of the solutions devised by designers to 'align visions' of different stakeholders in performance-based process. In cases where BPS tools were used to mediate the communication with the 'non-energy expert', BPS tools were used to provide evidence and to 'translate' energy metrics to concerns that were relevant to different stakeholders who participated in the decision-making process ie. cost savings in operation can be invested in other expenditures (client-user 's concern); buildability and standards site needed to meet as-built energy performance (contractor's concern). Yet, there is a generalised concern about the credibility of as-designed estimations (and BPS results) in relation to discrepancies with as-built and in-use performance.

The key advantages of the ethnographic approach is that it enabled the comparison of case studies of design in action to identify the commonalities and differences in the design process enacted by designers, including how BPS tools were used in everyday design process (bottom up understanding of the circumstances that facilitate and that interfere with the use of BPS tools by designers). The use of theoretical informed propositions from philosophy of technology and human-computer interaction allowed the focused investigation of design processes without imposing any research agenda. Yet, the use of these theories enabled a focused constructivist investigation to identify the participant's views and experiences in real-time design process. The ethnographic engagement helped the researcher to avoid out-of-context interviews, observations, retrospective accounts, self-accounts and snapshots of the process so the use of BPS tools was linked to the concerns and drivers of the different stakeholders in the process (within and beyond the design team)- cultures and processes-.

The disadvantage of ethnographic work is the resources need to conduct the investigation: length of the immersion, access to the research setting, time/budget constraints, commitment of the research participants, asymmetry of data collected across the case studies (specific to comparative ethnographic studies). Qualitative research methods where the researcher creates scenarios and prompts problem-solving situations which prompt comparisons and consideration of real circumstances are alternatives to ethnographic work; for example board games, scenario setting during focus groups. These methods can help to identify situations, challenges and solutions that build upon the participants' experiences, requiring less resources in terms of time and access to participants than ethnography.

CONCLUSIONS

The ethnographic method enables an in-depth understanding of how processes unfold (behaviours, actions) as experienced by participants; and, more importantly, why that happens. In relation to this work, the detailed field data is relevant to illustrate the complex practices that surround the adoption of BPS tools in building design. The field data suggest that the project-specific circumstances, the drivers of the process, the regulatory panorama determine how the design process develops over time; and, how the design teams engage with BPS tools during the design process.

However, the reader should be cautious in transposing these findings to other situations. Transferability of the field finding is one of the potential limitations of ethnographic work. The specific circumstances and processes are not prescriptive or predictive of other case studies. The findings are specific to the context of analysis, to the specific case studies. Yet, in reporting in detail the circumstances of the case studies, participants, research design and analysis, the reader can understand the research circumstances and what it means to the wider context. Ultimately, the detailed descriptions of how BPS tools are used and why it happens in such way have a global relevance in generating insights aligned to HCI propositions: BPS tools are not 'ready-made tools', the designers use tools in unexpected ways in relation to the context of use. Ultimately, this ethnographic work has identified some of the challenges faced by design teams. It illustrates existing problems and solutions which can be the source of inspiration for the provision of design support, whether that is realised by low tech or high solutions.

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