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 de-

ployed 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 uncon-trollable, 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 commonali-

ties 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.

ACKNOWLEDGEMENTS

REFERENCES

Alsaadani, S and Souza, CD 2012 'The Social Component of Building Performance Simulation: Understanding Architects', *Proceedings of the Building Simulation and Optimization Conference. Loughborough*, UK, pp. 332-339

Angrosino, M 2007, *Doing ethnographic and observational research*, Sage, London

Baird, F, Moore, CJ and Jagodzinski, AP 2000, 'An ethnographic study of engineering design teams at Rolls-

Royce Aerospace', *Design Studies*, 21, pp. 333-355

Ball, LJ and Ormerod, TC 2000, 'Applying ethnography in the analysis and support of expertise in engineering design', *Design Studies*, 21, pp. 403-421

Berente, N, Baxter, R and Lyytinen, K 2010, 'Dynamics of inter-organizational knowledge creation and information technology use across object worlds: the case of an innovative construction project', *Construction Management and Economics*, 28, pp. 569-588

Berger, P and Luckmann, T 1967, *The Social Construction of Reality - A treatise in the sociology of knowledge*, Penguin, Middlesex, England, Harmondsworth

Borgman, A 2004, 'Focal things and practices', in Kaplan, D (eds) 2004, *Readings in the philosophy of technology*, Rowman and Littlefield Publishers, Maryland, pp. 114-136

Bryman, A 2008, *Social research methods*, Oxford University Press, Oxford ; New York

Buciarelli, LL 1988, 'An ethnographic perspective on engineering design', *Design Studies*, 9, pp. 159-168

Buciarelli, LL 2002, 'Between thought and object in engineering design', *Design Studies*, 23, pp. 219-231

Buciarelli, LL 2003, 'Designing and learning: a disjunction in contexts', *Design Studies*, 24, pp. 295-311

Buciarelli, L 2001, 'Design Knowing & Learning: A Socially Mediated Activity', in C, M, surname missing, initials missing and Newstetter, W (eds) 2001, *Eastman*, Elsevier, Design knowing and learning cognition in design education, pp. 297-314

Button, G 2000, 'The ethnographic tradition and design', *Design Studies*, 21, pp. 319-332

Chastain, T, Kalay, YE and Peri, C 2002, 'Square peg in a round hole or horseless carriage?', *Reflections on the use of computing in architecture*, 11, pp. 237-248

Clarke, JA, Johstone, CM, Kelly, NJ, Strachan, PA and Tuohy, P 2008, 'The role of built environment energy efficiency in a sustainable UK energy economy', *Energy Policy*, 36, pp. 4605-4609

Coyne, R, Park, H and Wiszniewski, D 2002, 'Design devices: digital drawing and the pursuit of difference', *Design Studies*, 23, pp. 263-286

Creswell, JW 1998, *Qualitative inquiry and research design. Choosing amongst five traditions*, Sage, London

Denzin, N and Lincoln, Y (eds) 1998, *Strategies of Qualitative Inquiry*, Sage, California

Denzin, N and Lincoln, Y (eds) 2008, *Landscape of qualitatite research*, Sage, Los Angeles

Van Drokenlaar, C, Dowson, M, Spataru, C and Mumovic, D 2016, 'Review of the regulatory energy performance gap and its underlying causes in non-domestic buildings', *Front. Mech. Eng*, 1(17)

Gibson, JJ 1979, *The ecological approach to visual perception*, Houghton Mifflin, Boston; London

Gorse, CA and Emmitt, S 2007, 'Communication behaviour during management and design team meetings: a comparison of group interaction', *Construction Management and Economics*, 25, pp. 1197-1213

Hammersley, M and Atkinson, P 1995, *Ethnography. Principles in Practice*, Routledge

Harty, C 2008, 'Implementing innovation in construction: contexts, relative boundedness and actor-network theory', *Construction Management and Economics*, 26, pp. 1029-1041

Hodder, I 2012, *Entangled: an archaeology of the relationships between humans and things*, Wiley Blackwell, Sussex

Ihde, D 2004, 'Phenomenology of Technics', in Kaplan, D (eds) 2004, *Readings in the philosophy of technology*, Rowman and Littlefield Publishers, Maryland, pp. 137-160

Lawson, B 1997, *How designers think*, The design process demystified, Oxford, Architectural Press

Lloyd, P and Deasley, P 1998, 'Ethnographic description of design networks', *Automation in Construction*, 7, pp. 101-110

MacDonald, IA, McElroy, LB, Hand, JW and Clarke, JA 2005 'Transferring simulation from specialists into design practice', *Proceedings of International Building Performance Simulation Association*, pp. 657-662

Pink, S, Tutt, D, Dainty, A and Gibb, A 2010, 'Ethnographic methodologies for construction research: knowing, practice and interventions', *Building Research and Information*, 38, pp. 647-659

Silverman, D 2005, *Doing qualitative research: A practical handbook*, Sage, London

Silverman, D 2006, *Interpreting qualitative data. Methods for analysing talk, text and interaction.*, Sage

Tweed, C 2001, 'The social context of CAAD in practice', *Automation in Construction*, 10, pp. 617-629

Wenger, E, McDermontt, R and Snyder, W 2002, *Cultivating communities of practice: a guide to managing knowledge*, Harvard Business School Press, Boston

Winograd, T and Flores, F 1987, *Understanding computer and cognition. A new foundation for design*, Addison-Wesley, Reading, Massachusetts,

Zapata-Lancaster, G 2010, *Zero Carbon Hub. Closing the gap between designed and built performance. Carbon compliance for tomorrow's new homes.*, Zero Carbon Hub, London

Zapata-Lancaster, G and Tweed, C 2016, 'Tools for low energy building design: an exploratory study of the

design process in action', *Architectural Engineering and Design Management*, 12(4), pp. 279-295