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CHAPTER 4

Developing industry 4.0 applications: a social construction of technology approach

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ABSTRACT

The design and development of Industry 4.0 applications requires focused research work and close collaboration with the industry. Such an approach requires a balance between technical work and social interactions with industry partners: a social construction of technology (SCOT) perspective providing a lens for understanding how joint optimisation of the technical with the social dimension may be achieved. This chapter explores work conducted on the BIM risk library project: a successful 3-year research collaboration to develop and launch a new BIM digital tool to assist designers with their health and safety work. Describing the activities undertaken, including ontology creation, industry workshops, software development and piloting of a digital tool, the technical and social interrelatedness is noted as critical to success. Application of concepts from the social construction of technology: technological frames, social groups, problems/solutions, closure/stabilisation and wider context further clarify the evolution of the digital tool from conceptual idea to prize-winning application. The aim is to reinforce the importance of a social constructivist approach to technology development for the construction industry; the insights and reflections of the chapter, including the identification of SCOT optimisation triggers, are useful for Industry 4.0 technology developers and researchers active in the field.

Introduction

Whilst industry 4.0 technologies in construction can improve knowledge sharing and efficiencies (Newman et al., 2020), challenges to widespread diffusion and industry uptake remain considerable (Oesterreich and Teuteberg, 2016). There are technical, practical and social challenges to developing, testing and launching a new technology for industry to use that need to be recognised by those involved (Collinge et al. 2020a). As a result, suitable industry engagement strategies and appropriate working relationships with technology developers need to be established. Therefore, whilst the open and unimpeded sharing of health and safety data and knowledge between individuals and across projects is of central importance to digital advancements, as advocated by standards such as PAS 1192:6 (BSI, 2018), the practical requirements of working with software vendors, construction companies and individual users of a digital innovation should be recognised. Indeed, whilst BIM applications are a driving force for industry 4.0 change (Oesterreich and Teuteberg, 2016), with health and safety being a primary research area (Hossain et al. 2018; Mordue and Finch, 2014; Ding et al. 2016), what methodologies, strategies and interactions to employ can be overlooked (Collinge et al. 2020a).

The aim of this chapter therefore is to examine this aspect of digital technology development and to understand it theoretically. The chapter reviews the award-winning BIM risk library project: a digital tool and accompanying library of data that draws upon expert knowledge, real construction project scenarios and the archive of the UK regulator for health and safety at work – the Health and Safety Executive (HSE) to improve health and safety in construction. The research project was the recipient of several awards recognising its` value and contribution to improving health and safety: buildingSMART (2020); Construction Computing Award (2021). Lessons to be learned from this project and insights regarding the development and launch of the technology are therefore of interest to Industry 4.0 developers and academics in the field of innovation and construction safety and health.

The chapter begins by presenting sociomateriality and the social construction of technology (SCOT): approaches to understanding technology development that recognises the importance of both technical and social interactions. Concepts from SCOT are presented, the chapter going on to present the BIM risk library research project and the methodological approach employed, with separate work activities being unpacked in social and technical terms. Application of SCOT concepts clarifies the interactions and work processes occurring, with SCOT optimisation triggers being identified as critical to work progress. A discussion reviews the project workflow holistically, noting how the evolution of the BIM risk library may be understood in sociotechnical terms, with specific approaches and processes being noted as key to success. A closing conclusions section draws the insights of the chapter together.

Social Construction of Technology (SCOT)

A large body of literature exists that addresses the intersection of technology, work, and organisations. Sociomateriality attempts to understand the constitutive entanglement of the social and the material in everyday organisational life (Orlikowski, 2007). The focus on relations between agents and the social and the material's inseparability are key features of actor-network theory (ANT), a methodological approach, rather than a "theory" derived from sociomateriality. ANT falls under the umbrella of sociology of technology: an approach for understanding human and technology interactions as a network (Orlikowski, 2009). A sociology of technology approach recognises the importance of interactions between people and technology: a focus upon joint optimisation and excellence in both technical performance and quality of people's working lives being an important principle. Sociotechnical systems (STS) studies have proposed a number of different ways of achieving joint optimisation based on designing different kinds of organisation where the relationships between social and technical elements lead to the emergence of productivity and well-being (Baxter & Sommerville, 2011). The term "joint optimisation" suggests that social and technical elements can be harmonised and balanced to optimise productivity, worker satisfaction, and safety, although challenges surrounding this have long been recognised (Pasmore et al. 1982). Concepts from the sociology of technology can account for the multiple interactions and influences that occur as innovations are developed and implemented: an "unpacking of the negotiations and alignments that constitute the implementation of new technologies and the practices that use it" being of primary interest (Harty, 2005, p.516). Scholarly work in the field has addressed the development of technology in diverse fields, including the bicycle (Bijker 1995), new scientific knowledge (Law, 1994), electricity networks (Hughes, 1983) and large scale infrastructure projects (Aerts et al. 2017). It has been noted that negotiations between social groups can transform technological artefacts (Bijker, 1992), with "processes of alignment" creating necessary components (Hughes, 1983; 1998). Law (1986; 1994) uses the phrase "heterogeneous engineering" as the production of relatively stable sociotechnical entities through the interconnection and aligning of diverse objects and actors.

The social construction of technology (SCOT) (Pinch and Bijker, 1984) presents an approach for empirically investigating interactions between people, technology, and institutions: technology being treated not merely as a stabilised object, but as an evolving sociotechnical composition comprising artefacts, people, meanings, and practices (Oti-Sarpong and Leiringer, 2021). A SCOT approach assumes that actors have interpretive flexibility concerning a technology they use; a technology is socially constructed and emerges from a dynamic heterogeneous network shaped by contextual factors (Oti-Sarpong and Leiringer, 2021). SCOT is operationalised through its constructs: Technological Frames; Relevant Social Groups; Problems and Solutions; Closure and Stabilisation, and the Wider Context (Bijker et al., 2012) (see Table 4.1).

Table 4.1: SCOT concepts

SCOT concept	Definition/Explanation
Technological Frame	The collective summarisation of individual interpretations of a technology is a product of thoughts, past experiences, and accumulated knowledge of similar technologies (Bijker, 1995; Leonardi & Barley, 2010).
Relevant Social Group	Individuals who interact with a technology form opinions of it that are proximate to the views of others also using technology. Relevant social group compositions are fluid and change as technology develops (Oti-Sarpong and Leiringer, 2021).
Problems and Solutions	Problems emerge according to technological frames of groups interacting with a technology. Solutions may be offered that then change a technology. Solutions can reduce interpretive flexibility and create firmer technology composition (Oti-Sarpong and Leiringer, 2021).
Closure and Stabilisation	Closure and stabilisation work together mutually in technology development: closure eliminates problem issues associated with technology; stabilisation results from a consensus of opinion emerging from social groups that no further work is required to change a technology.
Wider Context	Wider context captures contextual elements (e.g. geopolitical and socio-cultural environments, climate, legal regulations, conventions and norms) that shape sociotechnical interactions

	surrounding technology development (Oti-Sarpong and Leiringer, 2021). The concept embraces institutional artefacts (e.g. contracts, building regulations and codes) that are bound to the use of technology in a context.

For the purposes of this chapter, SCOT constructs will be used to understand the development of the BIM risk library and its` evolution. Harty (2005) noted that adopting new tools and processes in construction is a complex business, with little to guide the practitioner through the messy and contingent process of adoption and diffusion. This contribution illuminates a successful digital innovation trajectory for the construction industry (Winch, 1998) from a sociology of technology perspective.

The BIM Risk library

The BIM Risk Library project commenced in 2019 under the Discovering Safety programme of the Thomas Ashton Institute (TAI, 2020). The project aims to assist design and construction professionals to manage better their health and safety objectives via proactive use of digital technologies and mobilisation of information resources via a Prevention Through Design (PtD) approach (Yuan et al. 2019). Further information about the research project is located in Collinge et al. (2020b). By way of illustration, Figure 4.1 is a screenshot of the BIM risk library tool, showing a risk scenario for “struck by a falling prop”.

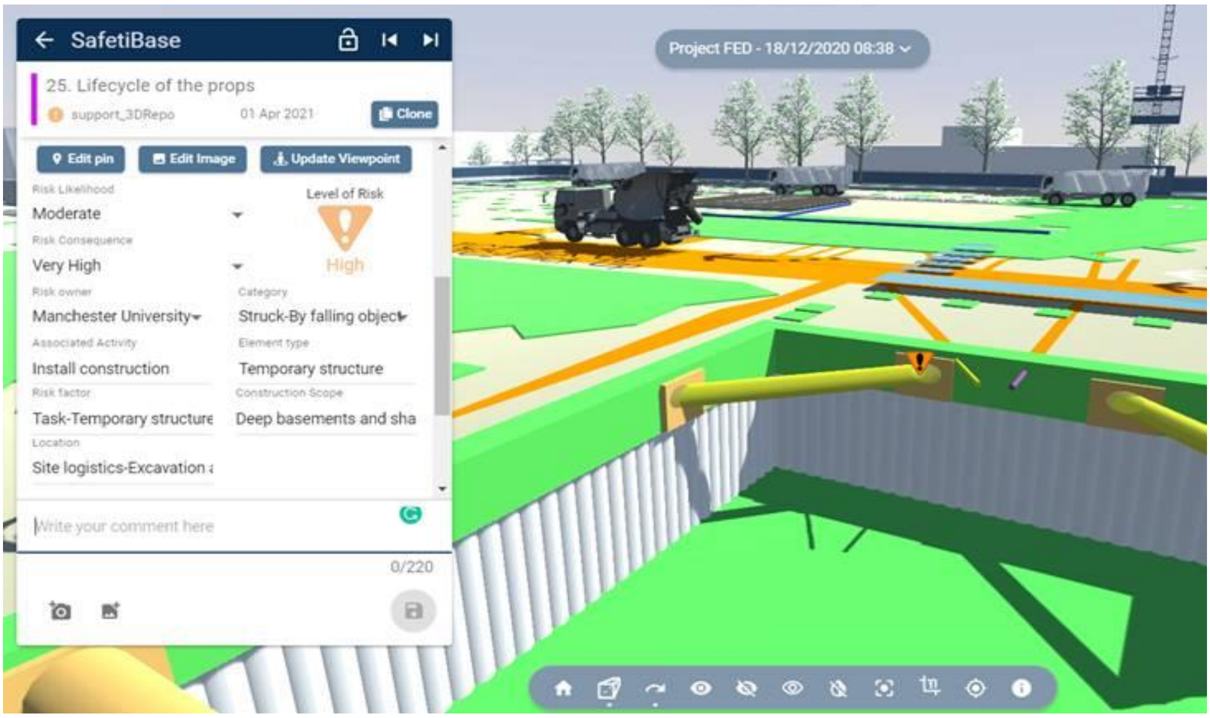

Figure 4.1: a screenshot of BIM risk treatment suggestion tool (RTST)

Through engagement with industry experts via Workshops (discussed below), two treatments suggested for this risk scenario were:

(1) Preliminary design - eliminate: "Eliminate the need for props (e.g. reinforced ring beam)"; and
(2) Detailed design - reduce: "Consider making the props part of the permanent works".

Figure 4.2 presents a flowchart of the principal work activities of the project, with specific technical or social activities being highlighted. A series of "SCOT optimisation triggers" are identified – these triggers being critical to the achievement of "joint optimisation" of social and technical elements (Baxter & Sommerville, 2011). Viewed holistically, there is a mixture of technical and social activities through the workflow. Whilst some activities (e.g. Literature Review) were neither social nor technical in character – being completed by the research team independently, others (e.g. Risk scenario mitigation identification) were social in that they required industry practitioner engagement in workshops to be successfully closed out. Similarly, some activities were purely technical (e.g. software interface development). Yet, such activities also had associated artefacts connected with them (i.e. contractual agreement with software vendor to develop the interface within a timeframe). Whilst the mix of technical and social activities was key to digital tool development success, the flowchart of activities and their associated artefacts deserve closer scrutiny and will be explored with reference to the SCOT concepts (Table 4.1). The following section focuses upon activities in the flowchart (Figure 4.2), providing more detail of the methodology employed and informative instances of social and technical interactions occurring.

Workflow Analysis

Literature & Software Review

The research team completed this work exclusively, so it cannot be flagged as social or technical in nature. Whilst NVivo software was used to produce a rich file of published work in the field, this activity is considered separate to the development of the innovative digital tool and library. Complete information about the literature review conducted is reported in Farghaly et al. (2021). Regarding the review of software packages on the market, one specific platform was selected as the most appropriate for the research project (see Software Platform development below).

Steering Committee Formulation

A Steering Committee was setup composed of research project stakeholders: the University of Manchester; the UK regulator for occupational safety and health (Health and Safety Executive); and representatives of leading construction companies. A primary source of membership was the BIM 4 Health and Safety Group (BIM4H&S): a UK industry group focused upon BIM and digital technologies to improve construction health and safety.

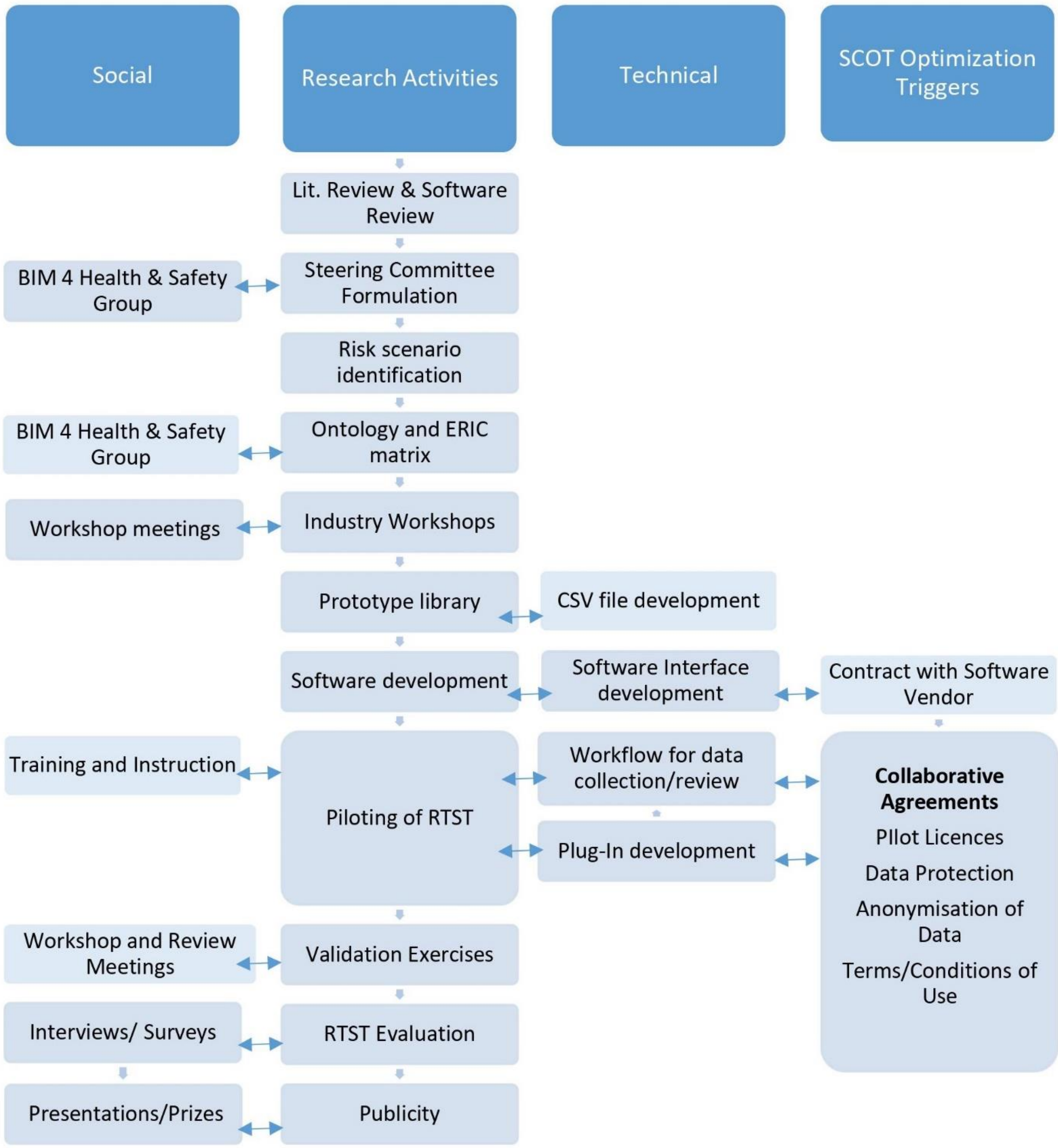

Figure 4.2: Flowchart of work activities

The BIM4H&S group was instrumental in work leading to the industry standard PAS 1192-6: 2018 "Specification for collaborative sharing and use of structured health and safety information using BIM" (BSI, 2018); a working link with the BIM4H&S group therefore being important for the research project. Having established an active link, attendance of meetings commenced, with ongoing work being presented at periodic intervals. This link was important for the research project, providing a direct communication link with industry figures managing construction health and safety in their organisations. This activity may be described as Social, connecting to the specific SCOT concept of Relevant Social Group (Table 4.1) that would use the digital tool on projects.

Risk Scenario Identification

Risk scenario identification was a research team activity: press releases and RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Regulations) reports from the HSE archive were reviewed to identify some common risk scenarios. One of the most common risk types in construction: falling from height in concrete in-situ buildings – was selected; nine risk scenarios relating to this risk were identified manually from the HSE sources. This task was completed by the academic research team exclusively.

Ontology and ERIC matrix

An ontology was formulated that mapped out the elements that make up a risk scenario requiring specific mitigations; the ontology concepts were rooted in industry guidance and previous academic work in the field. The mitigations for a risk scenario could be usefully mapped and referenced to different phases of the construction project – mitigations aiming to eliminate, reduce, inform, or control (ERIC) risks at the relevant phases of a construction project. Details of the ontology and ERIC matrix are provided in Collinge et al. (2020b). Validation of the ontology and matrix came from the Steering Committee and BIM4 H&S group: these Social Activities connecting to the Relevant Social Group and solidifying the Technological Frame and approach to be employed for subsequent data collection activity with industry.

Industry Workshops

The ontology and ERIC formulation were mobilised in expert industry workshops to populate the nine risk scenarios with relevant treatments. These were Social Group meetings which again served to affirm the Technological Framing of the ontology and overall approach of the research project. It should be noted that no contracts or specialised procedures were required to set up the workshops: individuals joined through professional interest, commitment to improving practices or as members of the Steering Committee. Resulting from the workshops, 162 treatments were identified to eliminate, reduce, inform, or control (ERIC) the risks covering four different stages of the project lifecycle: preliminary design, detail design, pre-construction, and during construction. One of these risks, "struck by a falling prop", and their associated treatments were noted at Figure 4.1 above.

Prototype Library

This dataset of 9 risk scenarios and 162 mitigations provided the basis for the prototype version of the library and the Risk Treatment Suggestion Tool (RTST) to be subsequently developed. The 9 risks and 162 mitigations dataset was saved as a comma-separated values (CSV) file. This work was a Technical Activity done within the research team, but it did not require specific sociotechnical processes or artefacts to be enacted.

Software development

Following the selection of one specific software vendor, a contract was set-up between the research project and the vendor so that the risk scenario ontology, ERIC matrix and dataset of risks/mitigations could be hosted on a BIM software platform via a specially designed interface (Figure 4.1). This critical step opened up the potential of sharing the research work with industry more widely, facilitating further population of the risk library with new risks and mitigations by designers working on multiple projects. The contract with the software vendor was vital to this task: an important insight here is the need to reserve project funds for software development work (if the expertise/capability is not within the academic research team). The contract may be described as a SCOT optimisation trigger: it drew in another Social Group (the software company) to share the same Technological Frame with a specific Problem being resolved through the Solution of an interactive interface on a BIM software package – called the Risk Treatment Suggestion Tool (RTST).

Piloting of RTST

It was necessary to pilot the Tool to further validate the work completed and begin the process of collecting more risks/treatments for the library. Piloting began in Summer 2020 with a number of industry partners using the RTST as part of their construction safety processes on live projects. Whilst each pilot project was uniquely different, each shared a common commitment to work with the RTST to identify risk scenarios and treatments and improve health and safety in the process.

Here again, we see Relevant Social Groups (architects; designers; engineers) being drawn into the sharing/shaping of the Technological Frame of the BIM risk library. It was through piloting work that the research team hoped to achieve a degree of Stabilisation for the RTST: this would be gauged by Tool assessment exercises and opinion gathering following the piloting phase. By the end of the piloting phase of the project (June 2021), a CSV file containing 401 treatment prompts for 31 risk scenarios related to 11 different risk categories had been added to the risk library knowledge base.

A number of SCOT optimisation triggers and artefacts were associated with the piloting work. As noted on Figure 4.2, training and instruction sessions (Social) assisted users of the RTST; plug-in development facilitated RTST use with different software packages (Technical) and creation of a Workflow for periodic data collection by the research team from project models that were then uploaded into a collective CSV file dataset (Technical) to grow the library. Equally important were the Collaborative Agreements drawn up with each Pilot project. These were approved by each party`s legal teams and signed by senior executives of the pilot organisations. These Collaborative Agreements were critical SCOT optimisation trigger artefacts: they covered issues such as data protection, the anonymisation of any personal/corporate information from the data shared with the library; the provision of free software pilot licences to cover the pilot period and terms/conditions regarding long term use of data for the benefit of all construction industry. These collaborative agreements were signed by senior executives of the pilot projects, representing a further important Social Group.

Validation exercises

Validation exercises aimed to assure the quality of the knowledge added to the library from the pilot projects. Two activities were conducted: an industry workshop and fortnightly review meetings with the research team and experts from within the HSE. These were Social activities with the Relevant Social Group where Problems and Solutions concerning use of the Tool could be openly discussed. An objective here was also a Stabilisation of the Tool and re-affirmation of the collective Technological Frame already established.

RTST Evaluation

Following piloting of the RTST and collection of data over 5 months, an evaluation and assessment process was undertaken. A questionnaire survey and interviews with users provided opinions and thoughts about the digital innovation and the overall research project. These activities were Social. The survey revealed that 85% of experts either agreed or strongly agreed that the RTST could positively impact design decisions and support the selection of appropriate treatments to mitigate health and safety risks. Furthermore, interviewees perceived that being able to add safety information to a BIM model of their facilities, and pinpointing where risks are on a model adds value to their current Safety Management process. Another benefit noted was the structured approach to inputting risk data and the opportunity for collaborative work which the Tool enabled.

Publicity

The research was presented at several national and international events (e.g. Digital Construction Week 2019; BIM for Water event 2019). The winning of several prizes created positive publicity: buildingSMART (2020) and Construction Computing Award (2021). These Social activities embraced further Relevant Social Groups previously unaware of the BIM risk library project, widening the Technological Frame further as a result.

Discussion

The chapter identified both social and technical work activities and the “processes of alignment” (Hughes 1983, 1998) taking place when an innovative technology is developed for industry. The mobilisation of SCOT concepts (Table 4.1) illuminated how the BIM risk library evolved from a research idea to a digital tool accepted by industry as a valid and useful new method for improving construction health and safety performance. Identifying SCOT triggers and artefacts (e.g. pilot licences; collaborative agreements) for successful work progress highlights the importance of these social and technical combinations for technology developers. The chapter also highlighted how social interactions informed specific aspects of the tool development. For example, the treatment measures for construction risks emerged primarily from the suggestions given by expert practitioners in industry workshops, whilst the foundational ontology was approved by the BIM 4 Health and Safety Group, a social gathering of experts and industry professionals.

Winch (1998) argued for more case studies of trajectories of innovation to identify who generates new ideas and how they are managed into "good currency", and this chapter provides tangible insights showing how new technologies may emerge from context-specific interactions (e.g. industry workshops; software vendor negotiations; piloting work) involving technical and social elements (Williams and Edge, 1996; Orlikowski, 2009). The insights validate the use of SCOT concepts (Table 4.1) to retrospectively examine the successful evolution of an industry 4.0 technology whilst also provding a useful template for designers and developers of the future.

The evolutionary nature of technology development (Linderoth, 2010) was tracked; the sociology of technology concepts (Table 4.1) clarifying the multiple constituencies and overlapping spheres of influence (Harty, 2005, p.517) occurring surrounding industry 4.0 application development. For developers of industry 4.0 technologies, the SCOT concepts are essential points of reference in the digital technology evolutionary journey. The SCOT optimisation trigger points that were pivotal to BIM library and RTST tool development had definite characteristics: legally binding contracts, committing parties financially and organisationally to some actions (e.g. participating as a pilot project; enhancing a software package; communicating regularly with the research team). When examined in detail, each trigger has clear links to each of the SCOT concepts (Table 4.1): addressing the technological frame, relevant social group, problems/solutions, closure/stabilisation and wider context issues of the social construction of technology. It is contended that these concepts are of primary importance for any industry 4.0 technology team with ambitions to design and develop a new technical innovation for the construction industry.

Conclusions

The chapter provided a social construction of technology (SCOT) analysis of work surrounding the design, development and launch of a new digital technology for improving health and safety work on construction projects: the BIM risk library and risk treatment suggestion tool (RTST). Although the BIM risk library and RTST is not yet a mainstream tool, recognition of the merit and value of the technology by national and international audiences means the insights of the chapter are useful and informative for construction industry 4.0 technology developers. The distillation of work activities into social and technical elements and use of the SCOT concepts clarified the processes underlying the evolution of the technology from an idea to a prize-winning application being used by industry on their projects. Therefore, the insights of the chapter are instructive and illuminating for industry 4.0 developers and academics looking to engage with the industry to develop new technologies to improve health and safety in construction.

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