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A foundational observation method for studying design situations

Observational studies of designers play an important role in engineering design research. Currently there is no standardised basis for comparing design research studies limiting reuse, reanalysis, replication, aggregation of data and ultimately impact. This paper begins to address these issues by introducing and discussing a foundational method for characterising observational studies. The three steps address capture, coding and analysis. The capture approach, promotes the treatment of study and participant *context* as well as the use of *multiple capture streams* to generate a holistic and flexible dataset that can be examined from multiple perspectives. The coding schema takes a novel multi-level approach, allowing the researcher to reduce their workload whilst still capturing both detailed and high level information. Then, the multi-level analysis approach allows flexible yet standardised examination of the dataset. In the paper the approach is introduced theoretically and then illustrated using an observational and experimental case study. Finally, the paper discusses the implications of such a method. Based on this, it is argued that adoption of this approach promotes rigour, reliability and standardisation for a range research foci and contexts and could provide one means for improving research impact, comparison and aggregation in the engineering design domain.

1. Introduction

This paper develops a foundational method for observational design research in order to improve the replication, reuse and the efficiency of empirical design studies.

A key area of empirical design research is that of design practice (Cross 2007, Finger and Dixon 1989a, 1989b, Horvath 2004), see for example Buur et al. (2000) and Valkenburg et al. (2009). Within this area there is a focus on the *activities* (Pedgley 2007, Dorst and Dijkhuis 1995) of the design practitioner supported by a range of empirical study (Robinson 2010a, Goodman-Deane et al. 2010). Observational approaches are one of the primary means of undertaking these types of study (Lethbridge et al. 2005). In this context they can be defined as any approach primarily focused on directly recording the phenomena under study.

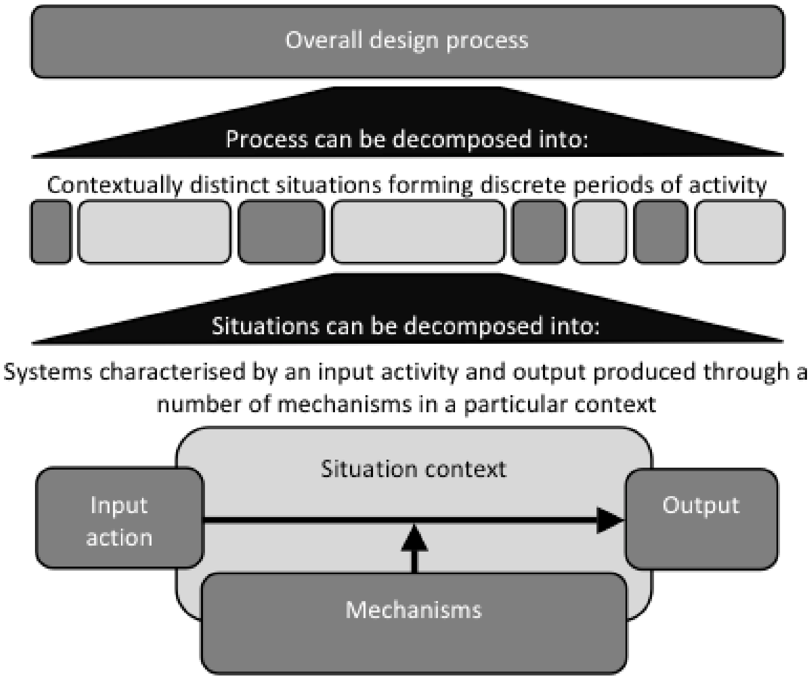
Critical to all these approaches is the rigorous and robust characterisation of practice (the practitioner, their environment and the wider context) to support theory building (Eisenhardt 1989, Briggs 2006), validation of experimental work (Bolton and Ockenfels 2008) and the improvement of research impact (Glasgow and Emmons 2007). However, in order to meet these aims it is critical to be able to bring multiple studies to bear on a single subject, triangulating results, accumulating significant sample sizes and varied complementary perspectives (Adelman 1991, Seale and Silverman 1997). As such, it is critical that methods, data and results can be reinterpreted, reused and built upon. In order to address these demands there are two main approaches to accumulating data, carrying out many identical studies or aggregating multiple different but related studies. The method proposed in this paper takes the later approach by developing a foundational method balancing *standardisation*, *flexibility* and *rigour* to support the aggregation and comparison of the many different, yet related, studies carried out in the engineering design domain each year.

In order to develop this method three areas are initially considered: the scientific paradigm (defining the methods scope), current issues in empirical design research, and the advantages and limitations of existing approaches (Section 2). With these areas established the method is proposed and illustrated with a case study (Sections 3 – 7). Finally a critical analysis is made of the proposed method and implications for design research identified (Section 8).

2. Background

The research philosophy guides and structures the worldview of the researcher and informs what is possible, guides assessment of the appropriateness of methods, and structures the development of theory (Robson 2002). As such, defining the underlying assumptions guiding the development of the proposed method is critical to understanding its scope and applicability. A *critical realist* perspective has been selected for this research for three main reasons. Firstly, critical realism and post-positivism (closely related) are the dominant philosophies in design research (Cross 2007), allowing the proposed method to be more easily integrated into current design research practice. Secondly, critical realism allows for a conceptual decomposition of the process under investigation into discreet situations, which can subsequently be further decomposed into a system with distinct elements – *action*, *output*, *mechanisms* and *context.* Figure 1 summarises this in the context of the proposed method and its relation to the design process.

Figure 1: A critical realist perspective with respect to the proposed method



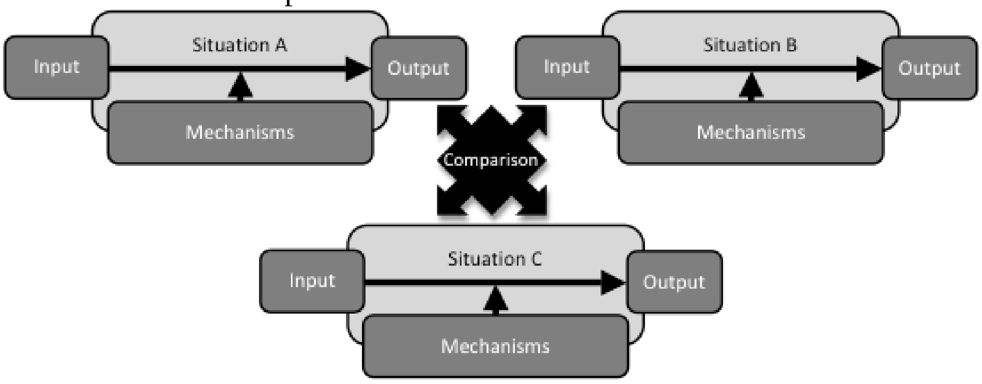
The final reason for adopting a critical realist approach (in the context of a foundational method) is that the situation-based model allows the researcher flexibility whist retaining common elements. This is key to the method proposed in this paper and is explored in more detail in the next section.

2.1. Standardisation Verses Flexibility

The aim of this work is: *to develop a foundational method for observational design research in order to improve the replication, reuse and the efficiency of empirical design studies*. Two key theoretical elements underpin this: identifying the necessary foundation for developing robust comparison, and identifying a balance between prescription and flexibility, to allow for effective standardisation without stifling unique research hypotheses.

Building on the critical realist model outlined in Figure 1, Figure 2 shows an idealised comparison where the systems have been recorded in a standardised manner. This allows for direct comparison and triangulation of the data without significant additional work.

Figure 2: An idealised comparison

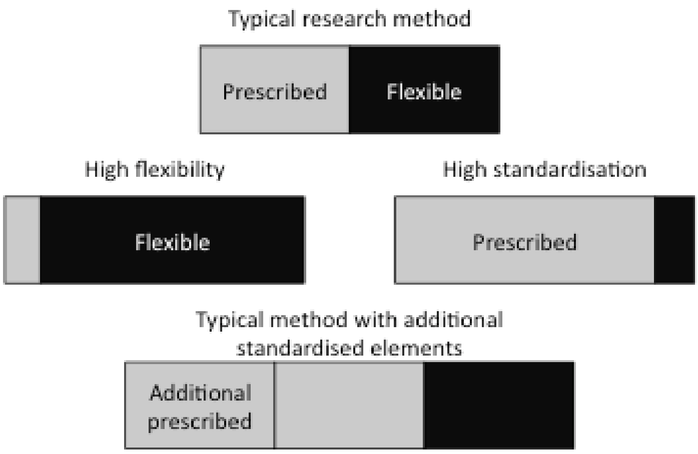


Using this model, it necessary to characterise the context, the inputs and the outputs in a standardised manner in order to effectively compare two, or more, systems. Comparing systems in this way allows deeper insight into the underlying mechanisms

– a key factor in developing effective theory, as emphasised by Briggs (2006) who states that: *"If we understand nothing of the causal mechanisms, then we can only achieve a given outcome by accident at first and by rote thereafter"* (p. 581).

The second element to consider in developing a foundational method is identifying a balance between prescriptive standardisation and hypothesis specific flexibility. The ideal case would be to add standardised parts without constraining the flexibility of the method. This is visualised in Figure 3 where additional prescribed elements have been added without significantly limiting the scope of the original approach. This holds true even for grounded 'high flexibility' approaches as although some additional work is required to add the standardised elements they do not constrain the construction of new methods, metrics or hypotheses. Hence this can be considered to form a standardised foundation upon which a range of methods or datasets can be built and compared.

Figure 3: The idealised role of a foundational method



With these foundational elements established it is necessary to consider the practical development of such a method based on the advantages and limitations of existing approaches.

2.2. *Current Issues*

A review of design research literature has been used to identify significant barriers affecting observational research. From this, six core issues were established and are listed here with a supporting reference for each (Table 1). This review has been reported in detail in [Authors Reference].

Table 1: Core issues affecting observational research

№	Issue	Example references
1	The need to link to theory	(Blessing and Chakrabarti 2009)
2	The need for effective contextualisation	(Adelman 1991)
3	The need for clear characterisation of the whole system	(Cook 2000)
4	The need for clear definition and reporting of the method	(Lloyd et al. 2007)
5	The need for the mitigation of bias through control or randomisation etc	(Goldschmidt and Tatsa 2005)
6	The need for field wide validation, replication and critical analysis	(Dyba and Dingsoyr 2008)

Examining these issues with respect to observation methods specifically reveals a number of practical problems affecting the characterisation of design practice. Dyba and Dingsoyr (2008) amongst others (Kitchenham et al. 2002, Blessing and Chakrabarti 2009) highlight a number of these problems, which are described in Table 2. The table provides a more detailed description of how the core issues manifest in the context of observational methods, refining the scope of Table 1 and expanding on those problems specifically related to method. In particular characterisation of the system (core issue 3) has been decomposed into sampling and research design, while mitigating bias (core issue 5) has been split into reflexivity and data analysis.

Table 2: Specific methodological problems

Problem	Description
Linking to theory	Effectively fitting the work into the wider field and associated theory
Describing context	Characterizing context to support generalization and links to theory
Sampling design	Avoiding sampling bias to effectively represent the population
Clear research design	Designing and reporting the research to support replication and validation
Data collection	Avoiding bias and information overload whilst giving a rich dataset
Reflexivity	Managing the research/participant relationship to minimize bias and experimental effects

Data analysis	Minimizing bias while giving results that can be effectively interrogated
Value of findings	Defining the validity, nature and role of the findings in the wider context

Based on these specific methodological problems and overarching core issues it is possible to assess the advantages and limitations of existing methods used to characterise practice.

2.3. Observational Approaches – Advantages and Limitations

There are many approaches to the characterisation of design practice, which attempt to accurately represent a given situation using various technical or methodological means. The authors have drawn on a review of the design research literature to bring together the most commonly used approaches, which are summarised in Table 3.

Table 3: Observational and other approaches for characterising practice

Approach	**Description**
Work diary	Participants report events either as they happen, reflectively e.g. Bolger et al. (2003)
Work sampling	Participants report events as prompted – can generate large data sets e.g. Robinson (2010b)
Applied ethnography	A combination of observation interviews and studies e.g. Atkinson and Hammersley (1994)
Auto-ethnography	Focusing ethnographic techniques on the self e.g. Cunningham (2005)
Shadowing/ observation	The researcher follows the participant and records their activities e.g. Singer et al. (2010)
Instrumented systems	Participant activity is automatically record on the computer e.g. ManicTime (2011)
Fly on the wall	Participant record themselves using video or audio e.g. Cooper et al. (2002)

Drawing on the core issues and specific problems described in Section 2.2 it is possible to assess the advantages and limitations of the approaches outlined in Table 3. In this, the authors recommend and draw on the work of Lethbridge et al. (2005), which contains a detailed discussion of a wide range of approaches.

Table 4 outlines the various advantages and limitations for each approach. It is to be emphasised that the specific limitations of each approach all detrimentally affect efforts to link the findings to theory or characterising the system as a whole. It should also be noted that although traditional ethnography is typically associated with a constructivist paradigm both applied ethnography (Ball and Ormerod 2000) and autoethnography (Cunningham 2005) have been developed to be compatible with a realist approach making them suitable for this comparison.

Table 4: Advantages and limitations of current approaches

Approach	**Advantages**	**Limitations**	**Relation to the core issues**
Work diary (Wild et al. 2010)	Provides insight over a long period without incurring significant demands on the researcher	Difficult to account for bias introduced through self reporting or contextual information	Difficult to account for bias (issue 5), difficult to validate, replicate or generalise (issue 6)
Work sampling (Robinson 2010b)	Generates large amounts of data without incurring significant demands on the researcher	Difficult to account for bias introduced through self reporting or contextual information	Difficult to account for bias (issue 5), can lack wider characterisation of the system (issue 3)
Applied ethnography (Ball and Ormerod 2000)	Provides insight into practice and is not tied to a constructivist paradigm	Difficult to effectively report the full dataset and can be affected by bias	Difficult to account for bias (issue 5), difficult to validate, replicate or generalise (issue 6)
Autoethnography (Cunningham 2005)	Provides unique insight by making the investigator the focus of the study	Difficult to account for bias, typically of a limited sample size and scope	As above but can also be linked to issue 3 due to the limited perspective
Shadowing (Bergstrom et al. 2008)	Can cover a wide range of attributes and requires no additional equipment	Difficult to account for bias and typically of a limited sample size	Issues 5 and 6 play a large role in studies of this type
Instrumented systems (Lethbridge et al. 2005)	Can provide accurate long term information on specific factors such as patterns of computer use	Difficult to address contextual information or effectively characterise the whole system	Difficult to effectively contextualise system use (issue 2) and its relation to other work (issue 1)
Fly on the wall (Lethbridge et al. 2005)	Unobtrusive and allows participants to acclimatise quickly with little disruption	Difficult to account for bias introduced through self reporting and limited scope	Issues 5 and 6 play a large role in studies of this type

Based on these advantages and limitations it is possible to imagine a combination of approaches that could reduce or even eliminate many of the limitations while maximising the advantages. This combinatorial concept and the maximisation/minimisation of advantages/limitations is discussed throughout the development of the proposed method. It should also be noted that an alternative approach would be the development of a standardised selection method for a specific situation through a weighting of advantages and limitations. However, this is outside the scope of this research and is, therefore, not further discussed in this paper.

3. Developing the Method

To develop the foundational method it is necessary to effectively mitigate the identified issues in the context of the overall approach outlined in Section 2.1. As such, this section introduces the main drivers behind the methods structure and scope, the key terms and underlying model, and the proposed method itself as well as an example implementation.

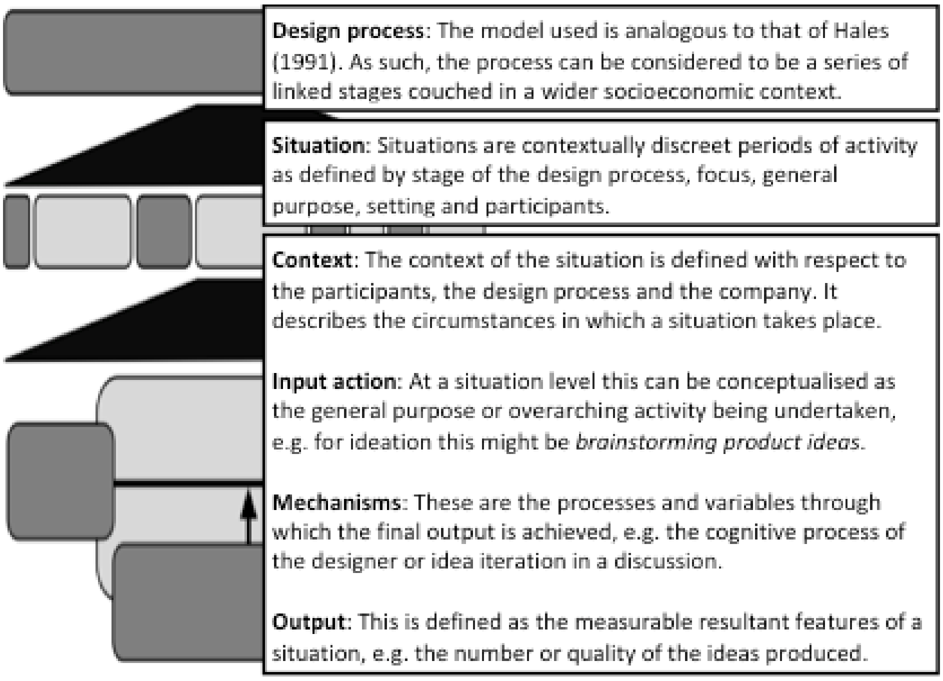
3.1. Creating a New Method

In order to address the methodological issues as well as the contrasting needs of standardisation and flexibility the method will build on elements of existing approaches to maximising the advantages of various methods. The three key pieces of research that have inspired the development of the proposed method are Robinson (2010a), McAlpine et al. (2011a) and Wasiak et al (2010). Of particular note is the accuracy and multi-level analysis strategy of Robinsons approach, the numerous capture sources highlighted by the work of McAlpine et al. and the multiple perspectives on engineering work enabled by Wasiak et al.'s approach. Further to this the proposed method builds on extensive prototyping of the approach carried out by the authors in [Authors Reference].

3.2. Theoretical Model and Terminology

In order to effectively combine multiple approaches as well as address the core issues and problems it is necessary to build on a common model. Figure 4 gives working definitions for the major terms used throughout this work and relates them to the general model put forward in Figure 1. In particular the concept of the situation has been developed from the work of Prudhomme et al. (2007). In this case the situation is defined in a more general sense, encompassing the design process as well as other non-design activities assessed using high level criteria, hence the change in terminology in order to avoid confusion. This is similar to the general criteria discussed by Visser (2009), who define the situation with respect to the design process, designers and artefact.

Figure 4: The model and associated terminology



Using this model there are two key areas to consider with respect to obtaining a balance between standardisation and flexibility. Firstly, decomposing the design process into discreet situations defined by common contextual factors allows the researcher to describe their study and periods within it in standardised manner without constraining the scope of their investigation. Further, by defining the granularity of the situation description it is possible to go from high-level overarching study to detailed evaluation within the same spectrum of standardised comparison, allowing for studies at different levels to be compared in a common reference frame.

The second key notion is the standardised conceptualisation of the situation with input, output, mechanisms and context (Figure 4). Again it can be envisaged that by considering each of these factors in a standard manner, research comparability could be improved. Although not explicitly explored in this work, this concept has been used to guide the development of the proposed method.

Drawing on these concepts the proposed method is characterised by an integrated three-stage approach: capture – characterising the context and providing the data for situation identification and investigation; coding – standardising the characterisation of the situation and providing a basis for developing a comparable dataset; and analysis – exploring the situation with respect to the given context. Although combining capture, coding and analysis in a single method is not in itself novel each stage draws on unique elements that contribute to a more effective overarching method – particularly with respect to standardisation. This integrated method allows for multiple research foci – fulfilling the flexibility demand –whilst maintaining standardisation and addressing the identified methodological problems.

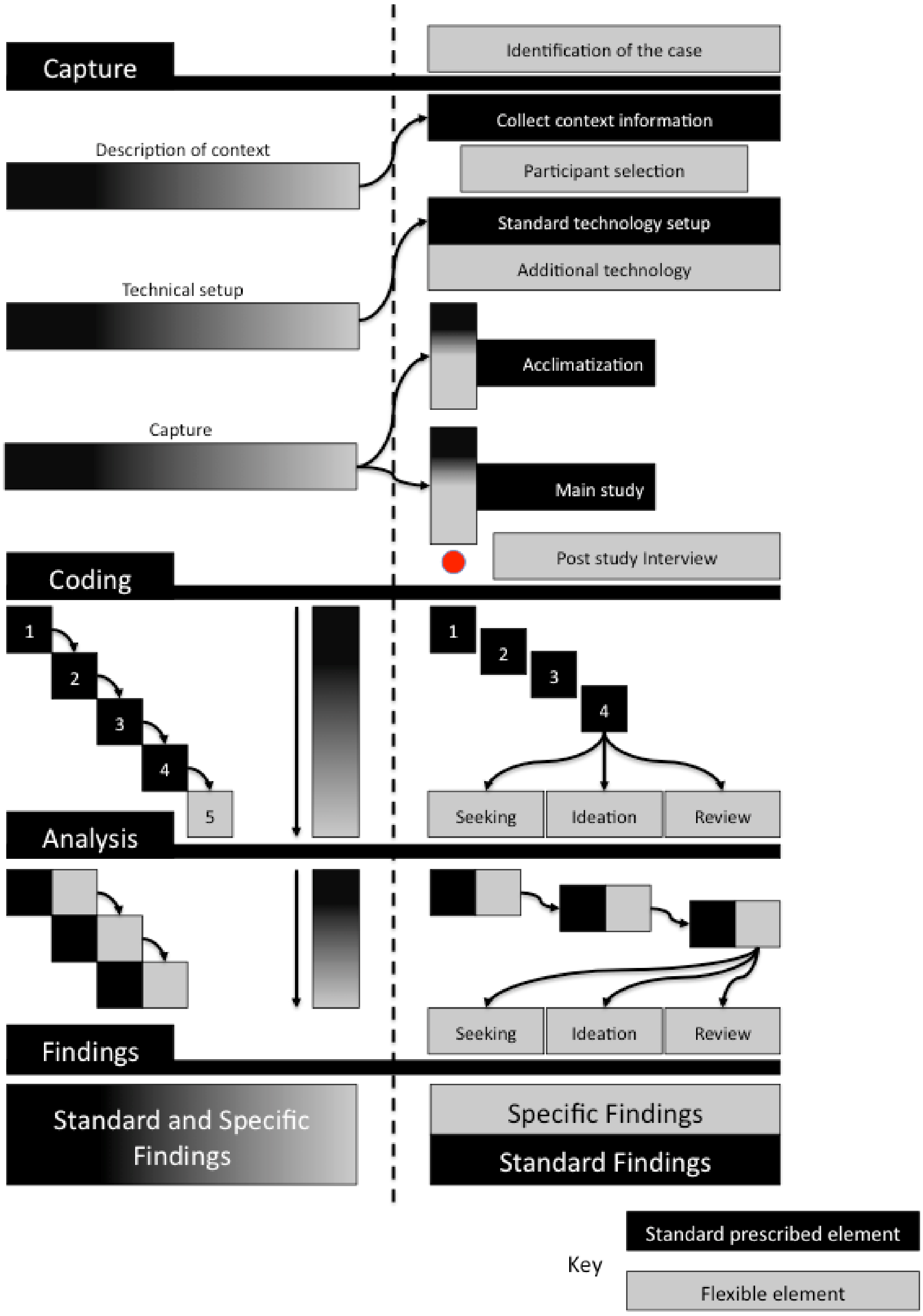
Finally it is important to define activity in the context of this work. This definition has been based on Activity Theory and has been adopted from the work of Bedny and Harris (2005): "*Activity is a goal-goal directed system, where cognition, behaviour, and motivation are integrated and organised by a mechanism of self-regulation toward achieving a conscious goal*." (p.130)

3.3. The Proposed Method and Case Study

In the context of a foundational method three main steps are necessary – capture (Section 4) which deals with the capture of context, technical setup and data collection; coding (Section 5) which introduces the multi-level approach; and analysis

(Section 6) bringing together the conflicting demands of flexibility and standardisation. Each of these steps is illustrated in using a case study example, detailed in Section 7. Figure 5 shows the methods main steps and links these to the specific work undertaken during the case study. It also illustrates how each stage of the method has both standardised and flexible elements allowing for the addition and development of specific research aims without losing the benefit of standardisation. It is envisaged that in many cases standard elements such as the capture strategy will overlap substantially with the specific demands of a particular research aim.

Figure 5: General method (left) and an example of its application (right)



4. Capture Strategy

There are three major aspects of the capture strategy: description of context, technical setup and data collection.

4.1. Description of Context

This section discusses the capture of various types of contextual information. Context is essential in order to develop the generalisability, relevance and external validity of a study (Kitchenham 1996, McCandliss et al. 2003, Allard et al. 2009), and plays a critical role in comparison, reuse and uptake (Shavelson et al. 2003). Further to this, Ahmed (2007) and Blessing et al. (1998) highlight the specific relevance of contextualising various factors for observational methods. In this section standard contextual factors are outlined to specifically aid generalisability and replicability (Dyba and Dingsoyr 2008, Dillon 2006). However, as discussed in Section 3 it is expected that additional hypothesis specific factors be recorded as necessary.

Although context is an important element affecting research, there are no widely accepted measures for characterising it. A number of key terms do, however, emerge from the literature: activity, organizational, cultural, social and historical (Wildemuth 1993, Klein and Myers 1999, Malterud 2001, Dym et al. 2005). Comparing the meanings of these various terms, it is apparent that organizational and cultural are similar. 'Organizational' is commonly used to express the company culture, while 'culture' is more commonly used to describe broader, participant related aspects of culture such as national culture or cultural background (Janssen et al. 2004). As such, by considering each factor from both a company and participant perspective, four main areas emerge: activity, social, cultural and historical. An important note here, is that the contextual information can be record either pre or post study depending on the demands of the specific research design and as such, the context first approach given in Figure 5 just one example.

4.1.1. Activity and Technical Environment

In the context of the standard parts of the method ‘activity’ measures cannot be defined without first defining the scope of the specific research question. However, the technical environment can be characterised in a standard manner and also plays a critical role in what activities the participant undertakes and their potential mode of action. As such, the key features of the participants’ environment need to be characterised in order to establish the technical and structural limitations affecting generalisability. For example, a setting with only one meeting room and a densely populated open plan office might produce an abnormally large number of informal meetings, which could be misinterpreted if not properly contextualised. Secondly, the bulk of participant work is likely to involve either their personal computer or logbook (McAlpine et al. 2011b). Based on this information it is important that these affordances are recorded in a structured manner.

Key features with regard to the standard parts of the method are the technical layout and resources in the workspace; the physical distribution of the participant, other workers and the overall layout of the working environment; the distribution of working time between the primary workspace and other areas e.g. the home or workshop; the technical affordances of the space likely to affect activity e.g. the distribution of whiteboards and other equipment. These are summarised in Table 5.

4.1.2. Social

Within this area the key factors required for baselineing a participant population are measured using socioeconomic status. This has a number of well established variables, which are used across research fields in order to define populations (Adler and Ostrove 2006, Pickett and Pearl 2001). These variables aim to give insight into factors such as, social norms (Streitz et al. 2001, Levitt and List 2007), social status (Jakesch et al. 2011), independence and interests (Shalley and Gilson 2004). The standard measures are summarised, together with potential means of finding this information, in Table 5.

Further to these personal factors, there are a number of characteristics required for comparing the company or specific setting to other studies in engineering design research. Factors associated with the social context of the company (i.e. factors that affect job complexity, demand, challenge, autonomy and complexity) (Shalley and Gilson 2004) include: funding, income source, market pressures, environmental factors, other monitory pressures and the composition of the company population.

4.1.3. Cultural

Cultural factors have two aspects, the national cultural background of the participant and the specific culture within the company. The need to capture these cultural dimensions is emphasised by Petre (2004) who highlights its effect on practitioner behaviour. In the context of assessing national cultural, the measure of cultural distance is well established (Shenkar 2001) and is used to define the participant population (Kogut and Singh 1988, Dow and Ferencikova 2010), including elements such as collectivism/individualism and group homogeneity (Janssen et al. 2004, Shalley and Gilson 2004).

With respect to company or the specific cultural artefacts present within the organisation from which the participants are drawn there are a range of factors to be considered, including hierarchy, level of formality, level of socialising and overall homogeneity (Guzzo and Dickson 1996, Stewart 2006). Other factors related to engineering design specifically include: pride in quality of work, competitiveness, type of design work (Wild et al. 2005), organizational aims or areas of support (Janssen et al. 2004), existing projects and practices (Lewis and Moultrie 2005). The specific factors recorded are summarised in Table 5.

4.1.4. Historical

In terms of the company, most of the historical factors manifest indirectly in terms of either the current social or cultural context. As such, there is little to directly assess in this aspect. Based on this, two areas are captured in the standard parts of the method – annual turnover and maturity – playing a confirmatory role by complementing the factors recorded in the social and cultural areas. In terms of the participant, the key historical factor is their previous experience and knowledge (Shalley and Gilson 2004, Jakesch et al. 2011). The specific measures are summarised in Table 5.

Table 5: A summary of the contextual features recorded by the standard method for the purposes of generalisability and replicability

Focus	**Company**	**Participant**
Technical Environment	Technical layout and resources of the work area(s) and overall layout of the work facility	Specific technical features of the participants work station, distribution of time across work areas
	Nº, distribution and types of co-workers	Use of resources – whiteboard, note pad, phone, bookshelves etc
Social	Funding/income sources, market pressures, environmental drivers, and other pressures	Age, occupation, highest level of education, gross individual annual income, level of property ownership
	The Nº and breakdown of employees, the Nº of hypothesis specific employees (e.g. design practitioners)	Area-based measure of sociometric status using e.g. ACORN http://www.caci.co.uk/acorn-classification.aspx
Cultural	Main aim(s) and scope, values and mission statement(s)	Nationality and national heritage
	Expertise, focus and level/type of engineering/design, past projects	Cultural distance measures - (Hofstede et al. 2010)
	Significant partners e.g. sister, parent or subsidiary companies/institutions and their role in management	
Historical	The annual turnover of the company	Formal education: subjects and grades and focus; Professional qualifications
	The maturity of the company	Professional experience over six months: role, duration, description

		Development within the current professional development framework

Although there are numerous other variables that can affect the outcome of a study the ones highlighted in this section have been prescribed as they form the core recognised variables necessary for defining a study and its population in a general sense and for relating the study to engineering design specifically. As such, the standard parts of the method allow for generalisation without delving into the more complex aspects of deep contextualisation – many of which comprise research areas in their own right.

4.2. Technical Setup

The standard aspect of the equipment selection and setup was based on the recent work of McAlpine et al. (2011a) who assess a range of capture technologies against their level of coverage v. data collection/analysis demands. From this work a number of optimal technologies for capturing activity were identified. In addition, the use of multiple capture pathways allows for the wide variety of situations likely to be encountered by participants in practice. This also partially mitigates the limitations on data recording often imposed in an industrial setting by providing a rich record of those periods were data capture is permitted.

The standard technical setup outlined here is based on the assessment of the participants' perception of their working practice (Section 4.1.1). This guides equipment distribution, although specific details of placement are strictly situational. As such, the standard technical setup focuses on the generic aspects of engineering activity e.g. the workstation and logbook. In this way, the standard setup provides a foundation for reuse while hypothesis specific additions can be used to address the needs of within study validity and insight. In order to give an effective foundation for reuse and generalisation the standard setup is designed to capture the widest range of possible activities whilst taking into account situation specific limitations. Table 6 outlines the standard capture perspectives – highlighting what each is recording and how they overlap. This overlap is important for synchronisation, providing redundancy and allowing triangulation during analysis.

Table 6: Standard capture perspectives and relevant technical approaches

Perspective	**Approach**	**What it is recording**	**Further information**
Participant	Synchronised camera 1	Front view of participant – high resolution, synchronised with other cameras	www.panopto.com (Panopto 2011) and standard HD web cameras
Workspace	Synchronised camera 2	Wide view of main workspace – audio and video synchronised with other cameras	
Detail of PC work	Synchronised screen capture	Live screen recording – high resolution, synchronised with cameras via e.g. panopto	www.panopto.com (Panopto 2011)
Overall PC usage	Long term data logging	Automatic recording of computer usage – usage, documents and applications	www.manictime.com (ManicTime 2011)
Participant view	Mobile camera	Participants view of situations away from the work station	e.g. Looxcie head mounted camera
Written notes	Recording of logbook	Participants notepad use and audio – writing and audio playback of logbook	www.livescribe.com (LiveScribe 2011)
Participant background	Work diary	Participant records activities not otherwise captured in structured form	Questionnaire e.g. Robinson (2010a)

From an engineering work perspective the capture strategy ensures that at least two complementary techniques capture each aspect of work, given in Table 7. The engineering work activities are taken from the literature, primarily the work of Hales (1987), Robinson (2010a) and Austin et al. (2001). This provides a robust record supporting redundancy and triangulation (Robinson et al. 2007, Seale 1999).

Table 7: Summary of engineering activities and the associated approaches

Engineering activities	**Approaches**	**What is captured**
Collocated meetings and collaboration	Recording of logbook	Meeting notes and audio of conversation
	Mobile camera	Audio and video from the participants perspective
Written communication	Synch. screen capture	E-mail and other messaging activity via computer
	Work diary	Other messaging activity
Distributed communication	Synch. cameras	Audio and visual of phone or computer use
	Synch. screen capture	Computer based video conferencing
Individual design work	Recording of logbook	Personal note making/working
	Long term data logging	Overview of computer usage
	Synch. screen capture	Detail of work carried out on computer
Project management activity	Long term data logging	Overview of computer usage
	Synch. screen capture	Detail of work carried out on computer
Participant detail	Synch. camera 1	Visual of participant demeanour
	Synch. camera 2	Audio and visual participant demeanour
Other	Work diary	Identifies events not otherwise recorded

A key non-technical issue is that of privacy, ethics and confidentiality. The standard capture setup has been designed to mitigate these limitations as much as possible. For example, approaches such as long term data logging allow at least a percentage of the data to be anonymised on collection rather than after coding. Further, the use of overlapping but linked recording mechanisms (e.g. multiple synchronised cameras) allow the participant to manage the recording process in a simple and transparent fashion as required. Finally, one of the strengths of the work diary allows the participant to anonymize information as they record it. However, as there will always be elements that are non-recordable in an industrial setting the proposed setup allows for these deficiencies to be recorded and reported in standardised manner.

4.3. Data collection

It is suggested that data collection takes place over a period that is split into three phases; an acclimatization phase, a study phase and a post-study phase. The standard setup and approach described in this paper aims to minimise researcher/participant interaction throughout this process for two main reasons, reflected in the design of the overall process. First, this reduces the impact of the standard elements on the hypothesis specific aspects of the study leaving the researcher as flexible as possible in their study design. Second, the minimisation of researcher/participant interaction is key to reducing experimental effects – often referred to as the Hawthorne effect. Essential, the act of studying human subjects has a range of effects on their behaviour, whether the study is observational or experimental (Kazdin 1998). These effects have many specific names and mechanisms of action (Holden 2001, Falk and Heckman 2009) but are generally referred to as Hawthorne effects, using the broad definition given by Adair: *"… The problem in field experiments that subjects' knowledge that they are in an experiment modifies their behaviour from what it would have been* *without the knowledge.*" ((Adair 1984) p.334). These effects have significant impact on studies involving people and must be accounted for either in the design of the study or through use of control and normalisation (Diaper 1990, Cook 1962). Where control is not appropriate – such as in observational or descriptive studies – steps must be taken to minimise these effects through other means. Minimisation of researcher/participant interaction (either through reduced contact or through blinded research design) is one, while acclimatisation is the second major approach – allowing the participant to return to as close to normal behaviour as possible before starting the study. Although this has its own affect on the study (Adair 1984), acclimatisation has been shown to be key in reducing the influence of these experimental effects (Leonard and Masatu 2006, Barnes 2010, Podsakoff et al. 2003). As such, the first phase of the foundational study design is that of acclimatisation.

4.3.1. Acclimatisation phase

The acclimatisation period is serves several purposes in the foundational method:

1. It allows for the minimisation of experimental effects. Three weeks has been shown to be sufficient acclimatisation for the normalisation of Hawthorne and other effects (Leonard and Masatu 2006, Barnes 2010, Podsakoff et al. 2003), although further study is needed to validate this in the specific context of engineering design.
2. It allows participants to become accustomed to the research equipment and procedures, such as, the recorded logbook (Table 7). Two weeks was considered the minimum for allowing these to become habit based on the work of McAlpine et al. (2011a). Further, by making the research procedure habitual the participant does not require day-to-day monitoring by the

researcher, reducing interaction (Adair 1984, Podsakoff et al. 2003).

3. It allows the researcher time to customize the standard technology setup, integrate any specific elements required and address any issues raised by the participant. This includes checking the equipment and preliminary data – reducing problems/data loss during the study.
4. It allows the researcher to gather participant feedback on the perceived effectiveness of the capture strategy. Such, reflective feedback is a key tool for improving rigour (Robinson et al. 2007).

It is suggested that participants undertake at least three weeks of acclimatization prior to the main study (Leonard and Masatu 2006). However, depending on the level of disruption associated with the hypothesis specific elements this could be extended and validated before starting the main study phase. In all cases the participants should record data and behaved as they would during the main study with the researcher checking the collected data for completeness at regular intervals. It is important to note here, that the acclimatization period could also be zero where the hypothesis specific demands define a scenario based or experimental study design, however, in this case control groups should be used to account for the subsequent experimental effects.

4.3.2. Study phase

With the acclimatization phase complete the study phase should start immediately – lasting as long as required for the specific research aim. Before the study starts each participant is given the opportunity to talk through any remaining issues/questions with the researcher. However, during the study itself participant/researcher interactions should be limited to reduce experimental effects (Podsakoff et al. 2003).

This minimisation is explicitly designed into the standard setup and overall method, with data collection automated where possible. At this phase it is sufficient to recommend that researchers consider this as a factor when developing the hypothesis specific elements as further constraint would limit the scope of possible research.

4.3.3. Post study Phase

In addition to the within study data capture, post study reflection – both immediately after the study and with respect to the final analysis – is an important aspect of validating the completeness and accuracy of the other capture perspectives (Robinson et al. 2007). As such, the standard method employs semi-structured interviews to explore these factors, fulfilling several important requirements:

- It allows the researcher to check if the participants' perceived their working practices to have been in any way unusual during the study.
- It allows the researcher to check that participants were still hypothesis blind where appropriate.
- It can allow participants to provide one type of validation with respect to the conclusions drawn from the analysed data.
- It allows participants to explain/expand on any incidents reported in the work diary and relate any issues or unrecorded events encountered during the study (only applicable to longer observational studies).

With the study complete the next step is the organisation, coding and analysis of the various data streams – addressed in the next section.

5. Coding Strategy

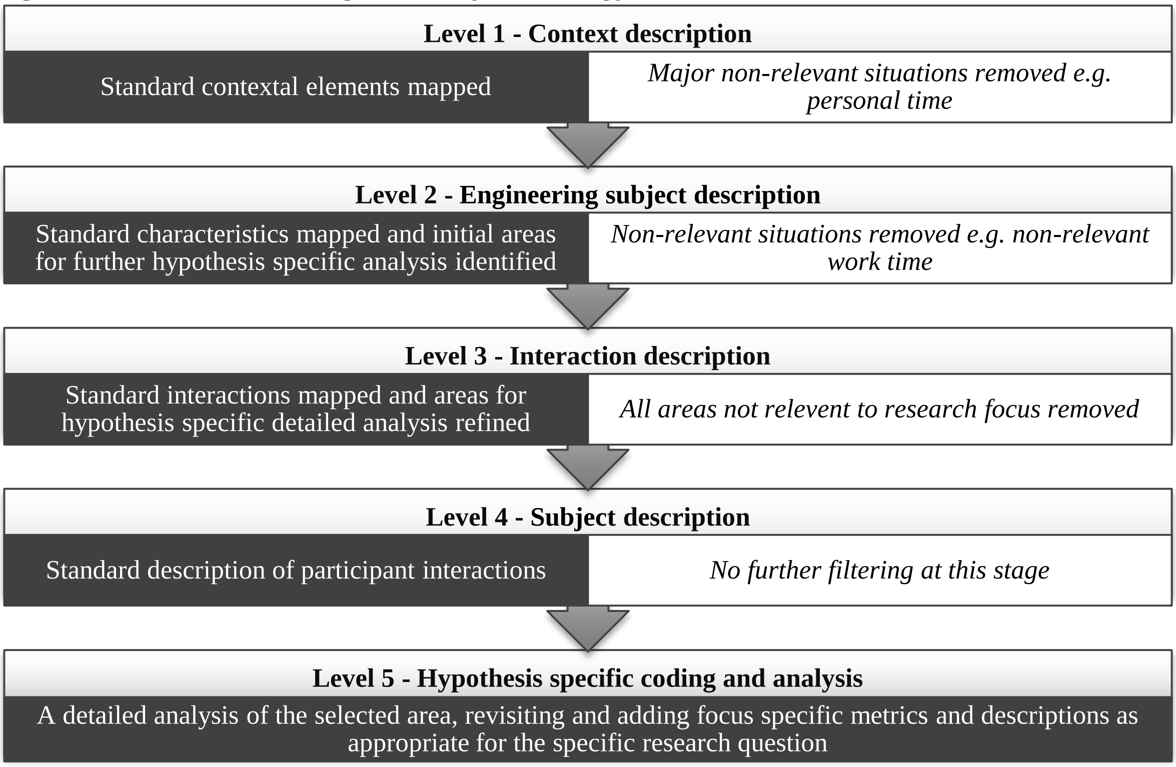
Due to specifying the combination of multiple capture streams a large amount of data is generated by the foundational methods standard elements. It is to be noted that it is not intended that all of this information be immediately utilised by the researcher, instead it forms the foundation for varied, multi-perspective reuse and reanalysis. As such, a streamlined approach is necessarily adopted by the proposed standard coding strategy to minimise workload whilst supporting comparison. This is facilitated by the ability to rapidly narrow the scope of analysis to detail specific situations or time periods without sacrificing the wider information contextualising such sections. This approach is realised using a multi-level coding and analysis strategy.

5.1 Multi-level coding and analysis strategy

The multi-level coding strategy consists of five levels of increasing detail. In order to capture the high level of detail required for the specific research aim, without overloading the researcher, the sequential levels of coding act as a filter, isolating periods that the researcher does not wish to pursue further. Thus it is possible to describe the entire data corpus at Level 1 and then rapidly narrow the scope by subsequently removing those elements irrelevant to the research – as dictated by the researchers focus.

Figure 6 outlines the five levels, describing the focus and the filtering strategy at each level (filtered elements are italicized). Each level guides the selection of standard data to be coded at the next level, thus reflection at each stage is essential to the strategies effectiveness. Reflection allows the researcher to identify and remove periods not relevant to their focus as guided by the coding strategy. This is conceptually linked to and builds on the foundation of Activity Theory. Activity Theory describes a system where discreet periods of activity are described using sequential levels of increasing detail, ending with unconscious operations and micro blocks (Bedny and Harris 2005). In this context the levels proposed by the standard coding method complement this model – defining the context in which an activity is taking place at various levels of detail allowing for comparison at any of the specified levels without prescribing or restricting the investigation of the hypothesis specific activity itself. As such, five levels were defined as the optimum balance between resolution and workload with more levels considered to be excessively prescriptive whilst offering little further benefit to generalisability. Figure 6 summarises the levels proposed as part of the standard method. At each level Figure 6 highlights the standard elements and how these integrate into refining and contextualising the hypothesis specific elements without constraining them.

Figure 6: Multi-level coding and analysis strategy



5.2 Coding

The multiple levels of the coding schema have been designed in order to maximise its practicability whilst giving the maximum benefit to the researcher and the wider field.

This is achieved by streamlining the coding process – only Level 1 is applied to the whole data set, with subsequent levels being applied to increasingly more limited periods. Further, by providing this multi-level contextualisation of the final period (defined by the specific hypothesis) the schema explicitly supports and promotes the triangulation of many different studies, data and approaches. Finally, the generality of the given codes makes them ideal for characterising a broad range of engineering design situations while also being accessible to design researchers working with a variety of different hypothesis and approaches.

To this end the levels have been designed in order to fulfil the key requirements for understanding and contextualising activity as defined by Activity Theory. In this context we can build on the definition of activity as: "*a goal-orientated system, where cognition behaviour and motivation are integrated and organised by a mechanism of self-regulation toward achieving a conscious goal.*" ((Bedny and Harris 2005) p. 130). Here, Bedny and Harris (2005) go on to define the key characteristics required for understanding activity: object (a tool or material object which the subject or group of subjects interact with) and subject (two or more subjects are characterised in terms of information exchange, personal interactions and mutual understanding). Combining this understanding with the contextual discussion from Section 4.1 four key areas emerge for defining a specific activity:

Context – the work environment, the type of interaction being undertaken, and the participants focus in terms of the generic engineering design process (Hales 1987). This also reflects a distinction between object and goal as discrete aspects of activity (Bedny and Harris 2005).

Engineering subject – the engineering design specific characteristics of participant focus and the overall nature of the exchange between subjects: problem solving and information exchange. These have been established within the engineering domain by the work of Wasiak et al. (2010) and Blandford and Attfield (2010), and have been synthesised and adapted to be generalisable for the standard method by reflecting on the underpinnings of Activity Theory.

Interactions – the object/objects forming the primary focus of the current activity, both individual and group. This has again been generalised based on the work of Cash et al. (2010)

Subject – the characteristics of exchanges between subjects: type of information exchange, personal interactions and mutual understating (Bedny and Harris 2005). These have been based on the works of Horvath (2004) and Wasiak et al. (2010), and have again been generalised with regard to Activity Theory.

With these four areas established, Table 8 summarises the codes used to characterise each area (definitions for each code are included in the Appendix). Each level is split into groups for clarity. Within each group codes are mutually exclusive. Level 5 is flexible and is thus not included in Table 8. Definitions are provided in the Appendix.

Table 8: The four levels of standard codes

Level 1 Context			
Group	**№**	**Code**	**Code options**
Interaction type 1	1	Individual/ group	0 - individual, 1 - group
Interaction type 2	2	Synchronous/ asynchronous	0 - synchronous, 1 - asynchronous
Interaction type 3	3	Co-located/ distributed	0 - co-located, 1 - distributed
Environment	4	Location	0 - normal, 1 - other
Focus 1	5	Design process stage	1 - brief creation, 2 - feasibility, 3 - design development, 4 - manufacture, 5 - testing, 6 - reporting, 7 - other
Focus 2	6	Focus: people / product / process	0 - other, 1 - people, 2 - product, 3 - process
Level 2 Engineering subject			
Group	**№**	**Code**	**Code options**
Problem solving	7	Goal setting	0 - not goal setting, 1 - goal setting
	8	Constraining	0 - not constraining, 1 - constraining

	9	Exploring	0 - not exploring, 1 - exploring
	10	Solving	0 - not solving, 1 - solving
	11	Evaluating	0 - not evaluating, 1 - evaluating
	12	Decision making	0 - not decision making, 1 - decision making
	13	Reflection	0 - not reflecting, 1 -reflecting
	14	Debating	0 - not debating, 1 - debating
Information exchange	15	Recognising need	0 - not recognising need, 1- recognising need
	16	Interpretation	0 - not interpreting, 1 - interpreting
	17	Validation	0 - not validating, 1 - validating
	18	Seek/ request	0 - neither, 1 - seeking, 2 - requesting
	19	Using information	0 - other, 1 - informing, 2 - clarifying, 3 - confirming
Management exchange	20	Managing	0 - not managing, 1 - managing
Level 3 Interactions			
Group	**№**	**Code**	**Code options**
Audiovisual	21	Audio only	0 - not interacting with X, 1 - interacting with X
	22	Visual only	
	23	Audiovisual	
Documentation	24	Formal	0 - not interacting with X, 1 - interacting with X formal/informal split defined by Hicks et al. (2002)
	25	Informal	
Physical	26	Environment	0 - not interacting with X, 1 - interacting with X
	27	Tools	
	28	Design representations	
Level 4 Subject			
Group	**№**	**Code**	**Code options**
Type of exchange	29	Opinion/ orientate/ suggest	giving or receiving: 0 – other, 1 – opinion, 2 – orientation, 3 – suggestion
Understanding	30	Agree/disagree	showing: 0 – other, 1 – agreement, 2 – disagreement
Personal 1	31	Antagonism/ solidarity	giving or receiving: 0 – other, 1 – antagonism, 2 – solidarity
Personal 2	32	Tension/ tension release	showing: 0 – other, 1 – tension, 2 – tension release

6. Analysis Strategy

The intent of the analysis strategy is not to fully analyse all the data captured and coded in Sections 4 and 5. Instead, analysis is tackled in stages either by the researcher carrying out the study or by a third party. This avoids overloading the researcher, whilst also making the large amounts of recorded information manageable by approaching it in stages. However, in order to achieve this result there are a number of standard steps that need to be taken to ensure rigour and completeness: alignment, layered analysis and reflection.

Firstly, the various data sources need to be aligned to a single consistent timeline as emphasised by Torlind et al. (1999, 2009) – for maximum benefit both standard and hypothesis specific sources should be aligned to a common timeline. This allows the researcher to maximise the potential of complementary data sources in three ways:

- It allows gaps in one source to be filled by another e.g. using mobile camera footage to follow the participant when they leave their desk – developing a more complete record.
- It allows multiple coded sources to be compared for a single event e.g. the code track for the participants logbook could be compared to the track for the mobile camera in order to refine the final coding – developing a more rigorous record.
- It forms a better foundation for generalisability, replication and reuse by relating the standard and flexible elements of the study to a single core unit – in this case the timeline.

Synchronisation and alignment requires a core timeline for consistency. For example, using the standard record of the computer screen (Table 7) to form a master timeline in VCode (2011, Hagedorn et al. 2008) (or similar annotation tools) all other sources, both standard and flexible, can be combined. Although the selection of this primary source is not prescribed, and need not be one of the standardised sources, it is recommended that the selected source is the most individually complete and comprehensive – minimising additional combinatory work. In addition to the methodological advantages of combining the sources onto a single master timeline, this streamlines the analysis, export and comparison process. With the various data sources aligned it is possible to start the analysis process. The standard method proposes three levels of detail and complexity.

The first and least complex level is the high-level quantification of the standard codes. This can include the total time each code accounted for, the number of instances, and overall trends. This high-level analysis follows the same approach and structure as outlined in Figure 6 i.e. analyse codes level by level, eliminating areas not of interest at each level as required. This allows for a standard baseline to be created, against which other studies using the foundational method can be compared.

Secondly, with the high-level analysis complete the next stage is to consider groupings of related standard codes. This level can be used to draw out deeper comparisons and to define more complex activities or situations. For example, using a combination of standard codes to describe a key situation allows for the subsequent identification of similar situations in other datasets utilising the foundational method and, as such, provide the basis for multi-perspective examination and triangulation. This again, allows pattern, frequency, total time or other aspects to be analysed for each group of codes. Groups are identified based on the following standard steps; each step is illustrated using the case study as an exemplar:

1. Define descriptive definitions of areas of interest – in this case tasks within the engineering design process as defined by Hales (1991).
2. Allow groups of codes to emerge from the data for the defined areas of interest (this can include multiple groupings) – In this case, conceptual design is defined using six combinations of codes. For example, two groups are: 'group', 'design dev', 'focus – product', 'exploring', referring to a group brainstorming activity, and 'individual, 'design dev', 'focus – product', 'exploring' referring to an individual ideation activity.

3. Reflect on the allocation of the groups of codes to ensure that the selected definitions are appropriate and further definitions do not need to be considered for the selected research focus. This is an important step as there can be large numbers of combinations for a single definition (depending on the code level to which the groupings are defined).

Thirdly, the standard codes can be used as the basis for detailed analysis if they are considered sufficient for the hypothesis specific part of the study – defined as Level 5 of the schema.

Finally, with the analysis complete it is necessary to reflect on the validity, reliability and limitations of the data. However, as the focus of the foundational method is to support replication and comparison rather than explicitly address internal validity, the means by which the researcher establishes these parameters (validity, reliability, limitations etc) is flexible. With respect to the foundational method it is sufficient to establish that the information that has been coded is representative of the data, as such, appropriate inter-coder reliability checks should be undertaken.

7. A Case Study Comparison

In order verify the efficacy of the foundational method in the context of design research the case study examines the method from two perspectives. First, the method's potential for comparing and triangulating studies of different formats is examined using an observational study of practice and a laboratory experiment. Second, the method's potential for supporting varied research foci is investigated. Supporting both of these perspectives were two populations, one of practitioners based in a Small to Medium sized Enterprise (SME) and one of student engineers.

7.1 Perspective 1: Study Format

Here two studies are compared, one an observational study carried out in practice over the period of three weeks and the other a discreet experimental study focusing on student engineers for just four hours. Both studies were carried out based on the foundational method with adaptations for the specific setting and research questions.

In the context of the observational study the situations described fully at Level 4 are contextualised by the preceding levels and can be defined in terms of the combination of codes. As the aim of the observational study was to identify and characterise key design situations such as ideation, design review meetings etc. the coding schema allowed for the rapid narrowing of scope while retaining the overview of the whole study period.

Conversely as the experiment study was defined in detail by its associated research questions and could subsequently be rapidly characterised by the standard coding elements. To elaborate, the higher levels of the coding strategy were predefined or highly limited by the research question and were therefore primarily used in a confirmatory role. Further, as the higher levels could thus be coded rapidly specific codes could be examined with little additional effort. Table 9 describes each of the case studies in relation to the foundational method, highlighting how it can be adapted, streamlined and applied to different contexts whilst retaining comparability.

Table 9: The case studies in relation to the foundational method

Foundational method	**Observational study**	**Experimental study**
	Context	
Personal	Carried out prior to the study using questionnaires as no fixed hypothesis	Carried out post study to maintain hypothesis blindness using questionnaires and other tests for hypothesis specific information
Wider population	Carried out prior to the study using interviews with company management	Carried out independently based on available data from the host university
Technical setup	As prescribed	As prescribed but forgoing mobile cameras due to the restricted setting

Capture		
Acclimatisation	Three weeks for each participant to minimise effects	None due to the study design, instead control groups could be used
Study	One week per participant with full freedom (98 hours total for the three)	Four hours with each experimental team – predefined group and individual work
Post study	Interview assessing the data, and reported work of the participant	None
Coding		
Level 1	100% of time coded at this level	Specified by the study design thus not coded
Level 2	80% of the time coded at this level	Guided by the study design, only a selection of codes were encountered (4 of 14 Level 2 codes used)
Level 3	Focus reduced to group work with a focus on the product: 34% coded	Guided by the study design, only a selection of codes were encountered (2 of 8 Level 3 codes used)
Level 4	Specific situations: only 4.2% coded: one ideation, one information seeking and one review situation (250 min)	Coded fully for each of the studies
Specific	None originally – then specific codes from the experiment applied situations in the observational study	Additional codes added for ideation, information seeking and design review based on the research questions
Analysis		
Synchronisation	As prescribed, using the participant camera as the central timeline	As prescribed, using the participant camera as the central timeline
High level	Individual codes used to describe overall design activity and process	Level 1 used to compare experimental context to observation study
Groupings	Groups of codes used to describe specific situations for comparison – ideation, seeking and review	Guided codes (Level 2 and 3) used to link to the specific situations observed in practice
Detailed analysis	Specific codes analysed and then applied to the identified analogues situations from the observational study – ideation, seeking and review	
Reliability	Cohen's Kappa applied to check inter-coder reliability	Cohen's Kappa applied to check inter-coder reliability

A key feature of the foundational method, highlighted by Table 9, is that the experimental study can be immediately and directly related to similarly contextualised events from the observational study. This is born out when the data from the experimental and observational studies is compared. An example comparison is shown in Figure 7, which depicts an ideation period from the observational study similar to that from the experimental study as defined by Levels 1 – 4.

Further, by enabling this comparison the method allows for an improved understanding of the likely impact of findings from the experimental study on practice. In this case, the features of the experimental study could be matched to three similar periods in practice, which themselves could be assessed in the context of the wider process as shown in Figure 8 (similar periods are highlighted in grey). Figure 8 also shows design development and design review activity in the observational study (again based on Levels 1 – 4) as an example of how contextualisation with respect to the wider process can be developed.

Figure 7: Ideation in the observed case and in the experimental study

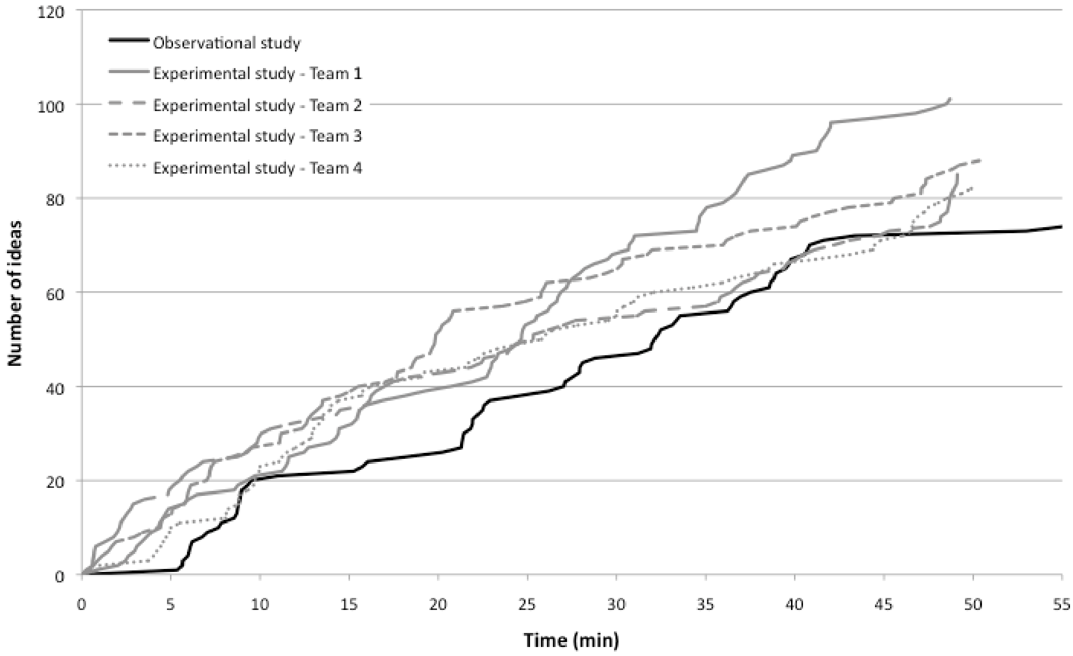
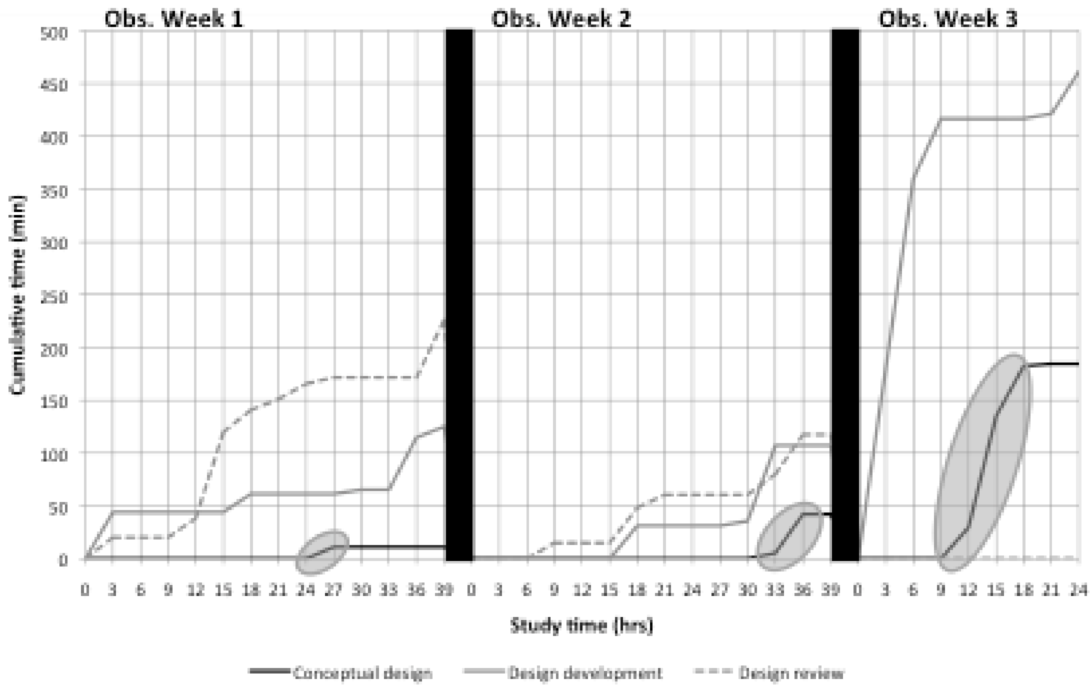


Figure 8: Identifying relations between the studies



7.2 Perspective 2: Research Focus

In this context four different research foci were considered: the overall design process, information seeking, ideation and design review.

7.2.1 Design process

In order to assess the ability of the foundational method to support a purely observational study of the design process a three-week study of practice was considered. This was designed and carried out as described by the foundational method with minimal changes in order to assess the scope of using the standard elements only – summarised in Table 9.

Based on this it was then possible to describe the design process encountered during the study based on the standard analytical steps (Section 6). Firstly, the individual codes allowed for a raw assessment of the types of work undertaken based on the total time spent on each activity e.g. focus (product, process people) and phase of the design process.

Secondly, combining the codes allowed for a more nuanced description of the design process and participant activity. With respect to the example of information seeking it allowed for the whole range of information behaviours characterised by Robinson (2010a) to be described in terms of combinations of codes. This resulted in approximately 45% of the participants' time being associated with information seeking activities of various types (Robinson 2010a). This closely, links to other estimates of information seeking in the extant literature (Robinson (2010a) – 56%, King et al. (1994) – 40-60%, Puttre (1991) – 32% and Cave and Noble (1986) – 30%), suggesting that the combination of standard codes was in fact sufficient to fully represent this specific research focus. An example of a combination of standard codes used to describe one type of information seeking activity is (the number of the relevant code is given in brackets (Table 8)): Individual (1), distributed (3), feasibility stage (5), product focus (6), solving (10) and requesting information (18). In this case the standard coding could allow Robinson or others to reanalyse the data with respect to their own work without significant recoding effort – instead reanalysis is achieved either by defining combinations of codes or by identifying areas of interest and then recoding them specifically.

This process of identifying extant research foci from the literature and then using these to define code groupings was used to assess the flexibility of the foundation method for each aspect of the design process (Hales 1991). Table 10 summarises these stages and the literature used as the basis for assessing the foundational method's application to each. This allowed for each aspect to be mapped across the study period and assessed both individually and collectively (With respect to the different research foci examined in the experimental context three main areas were considered:

Figure 9).

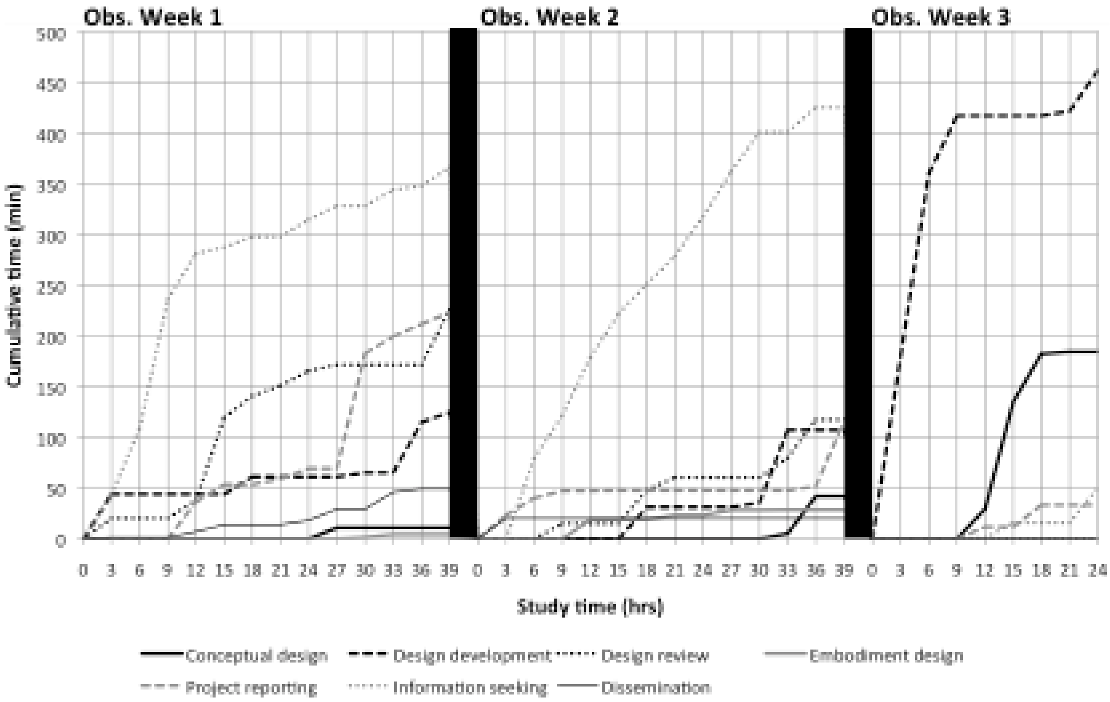
Table 10: Hales' stages of the design process related to the foundational method

Stage (Hales 1991)	**Description**
Conceptual design	Ideation and concept development tasks inc. brainstorming, idea selection and concept exploration (Howard 2008, Cash et al. 2011)
Design development	Development of a specific final concept inc. design refinement and problem solving (Carrizosa and Sheppard 2000, Kim and Maher 2008)
Design review	Reviewing existing work or future planning inc. review meetings and reflection on current designs (Huet et al. 2007b, D'Astous et al. 2004)
Embodiment design	Technical layouts and CAD configurations inc. CAD, prototyping and configuration (Scaravetti and Sebastian 2009, Chenouard et al. 2007)
Testing	Not considered as not present in the observational study
Project reporting	Formal collation and dissemination of structured reports inc. lessons learned, reports and formal presentations (Wild et al. 2005, Haas et al. 2000)
Information seeking	Searching, requesting, synthesizing and evaluating information inc. examination of records and applying data (Robinson 2010a, King et al. 1994)
Dissemination	Informal communication of decisions, plans or progress inc. email,

	conversations and shared workspace (McAlpine 2010, McAlpine et al. 2009)

With respect to the different research foci examined in the experimental context three main areas were considered:

Figure 9: Overall participant activity during the observational study



7.2.2 *Information seeking*

In this example the research question was focused on examining the role of information seeking activity and sources on design performance. In this case the experimental context was described as 5 (design development stage), 7 (product focused) and 10 (solving) with either 18 (seeking/requesting) or 16 (interpretation) as the forms of information exchange. The specific Level 5 codes based on the work of Robinson (2010a) served as the basis of comparison when examining the results.

7.2.2 Ideation

In this example the research question was focused on examining the need for creative stimuli by assessing the change in the rate of idea generation over time. Here, the context was defined as codes 1 (group), 4 (in a meeting room), 5 (feasibility stage), 6 (product focused) and either 9 (exploring the problem) or 10 (solving the problem). Further, Howard et al. (2010) was also characterised using the standard method – facilitating a comparison to this existing dataset from practice. As such, the only Level 5 code was for idea generation. An example of the results is given in Figure 7.

7.2.3 Design Review

In this example the research question was focused on the use of artefacts during a design review meeting. Here, the codes 1, 4, 5 and 6 were used to define the context while Level 2 and 3 codes were used as the basis for the analysis. The results were then compared to the work of Huet et al. (2007a).

8. Discussion

This section discusses the success or otherwise of the foundational method in addressing the identified methodological issues (Table 2) before examining the limitations of the method generally and this work specifically.

8.1 The Foundational Method

The foundational method proposed in this paper aimed to *improve the replication, reuse and the efficiency of empirical design studies*. This was achieved by addressing the specific problems identified in Table 2: linking to theory, describing context, sampling design, research design, data collection, reflexivity, analysis and value of findings. The foundational method combines the benefits of both standard and flexible elements using multilevel capture, coding and analysis. This allows the flexible examination of hypothesis specific detail whilst also providing rich contextualisation of the situation under study and a standardised means of comparison and triangulation.

The capture step firstly formalises the reporting of context in four areas – activity/technical, social, cultural and historical. Secondly, a standard multi-perspective capture approach defines numerous complementary sources. Finally, an acclimatisation period is incorporated into the typical observational approach as part of the data collection process to reduce experimental effects. These support the generation of a robust dataset, which can be analysed at multiple levels of detail and expanded to include a wide range of specific research foci.

The multilevel coding and analysis strategy allows for a streamlined contextualisation of the wider study without stifling flexibility by progressive filtering at each level of the process. This enables a rapid interrogation (and comparison) of the dataset at multiple levels of detail whilst maintain context and methodological robustness, and minimising additional workload.

The multilevel analysis provides a standard foundation for replication, reuse and comparison by aligning and baselineing the dataset. Further, the multilevel strategy allows the researcher to interrogate the data at increasing levels of detail at little additional cost. This enables an analysis of the coded data, which supports both high-level contextualisation and rapid analysis of large bodies of data while also supporting flexibility and overall rigour.

Collectively these three steps combined in the proposed foundational method support the standardisation of key comparative data for a wide range of possible studies. This is critical to improving reuse and laying the foundation for meaningful comparison and triangulation – all key areas for the improvement of design research methods (Blessing and Chakrabarti 2009). Further to this the foundational method offers the pragmatic benefit of allowing the researcher to more effectively structure and navigate through the large amounts of data generated in observational studies and significantly expand on the recommendations of Blessing et al. (1998). Finally, the multilevel approach allows the proposed method to be extremely flexible in terms of research focus without sacrificing the benefits of standardisation or rigour as highlighted by the case study and discussed throughout.

The proposed method addresses many of the problems identified in Table 2. In particular it supports linking to theory, contextualisation, standardisation and clarity of research design, mitigation of bias, clarity and scope of data analysis, and improved value of findings. However, there is still a clear need for significant work in addressing many of the identified problems. This is summarised in Table 11, which highlights how the problems identified in Table 2 have been addressed by the foundational method and where the need for further work has been identified.

Table 11: Issues and their mitigation by the foundational method

Problem	**Description of mitigation**
1. Linking to theory	Contextualisation and multi-level analysis allow situations to be linked to existing work and wider theory by offering a standard basis for comparison
2. Describing context	The key contextual information and multilevel coding significantly improves contextualisation of the hypothesis specific elements
Further work	This requires further development in order to identify what specific information is most valuable when recording context in the design domain
3. Sampling design	This is addressed by standard contextualisation of population and again allows for more effective comparison and triangulation of similarly described studies
Further work	There is a need to develop and validate the links between sample design and the elicited contextual information
4. Clarity of research design	Description of the coding schema and the ability to define the level or area of analysis from combinations of codes supports standardisation and clarity
Further work	There is need for significant work in the development of links between levels and the development of relationships between individual and groups of codes
5. Mitigation of bias in data collection	The acclimatisation period and multimodal capture allow for reduced experimental effects and triangulation of multiple sources, reducing bias
6. Reflexivity	The semi-automated nature of the capture strategy eliminates the need for researcher/participant interaction during the study period

Further work	Work is needed to understand the impact of experimental effects over time in the engineering design domain and to subsequently optimise acclimatisation
7. Data analysis	Multilevel coding and analysis coupled with multimodal capture allow characterisation of the system at multiple levels of detail reducing bias
8. Value of findings	The ability to give detailed analysis for selected situations while retaining high-level contextual information supports replication, reuse, triangulation and critique – key areas for improving theory and research uptake

8.2 Limitations

There are several limitations of the proposed method. The primary weakness is in validating the range of possible sample sizes to which the foundational method can be applied. However, the multilevel approach allows the researcher to define the sample size required (from statistically significant to single case) and then apply the appropriate level of coding and analysis without losing the advantages of standardisation, contextualisation and additional detailing.

A second issue requiring further investigation is the period of acclimatization. Although this has been the focus of some investigation in other fields there is little information on the amount of time needed and specific effects encountered in the engineering design domain. An improvement would be to carry out a series of studies to explicitly determine the extent of the disruption caused by experimental setup and the length of time required for participants to return to normal practice. In the context of the case study the acclimatisation period was considered sufficient as evidenced by participant's checking private emails and other personal activities. However, for each specific context the acclimatisation period should be designed accordingly.

Although the foundational method does introduce some additional methodological and standardisation demands the flexible multilevel capture, coding and analysis strategies allow the method to be rapidly adapted to most research contexts where the focus is participant-centric. This has been demonstrated via the case study. However, the true scope of the methods flexibility in terms of sample, compatible research topic and approach are yet to be fully validated.

Finally, a more specific limitation of the work reported in this paper is the scope of the case study. In the context of the proposed foundational method true validation would require two elements: a systematic comparison across all possible variables and study contexts demonstrating each aspect of the method; a rigorous comparison of the foundational method against all relevant alternative approaches to improving reuse, replication and comparison. Both of these elements are significantly outside the scope of any one work and likely to only be established reflectively after multiple years of uptake, critique, implementation and comparison. As such, the case study presented in this paper does not claim to validate the method, instead it verifies the applicability of the foundational method and provides an example of how the comparison process can be used to give new insight.

9. Conclusions

This paper outlines the creation of a foundational method for supporting the aggregation of observational studies in the engineering design domain. The method introduces a multilevel approach to capture, coding and analysis and builds on pervious works including Blessing et al. (1998) and Robinson (2010b). The proposed method offers several key advantages for improving replication, reuse and triangulation. Firstly, the capture approach formalises the reporting of context and the use of multiple complementary sources in order to produce a robust dataset – allowing for *both* standardised contextualisation and hypothesis specific flexibility. Secondly, the multilevel coding and analysis strategies combine to promote theory building, and standardisation of contextualisation, comparison, triangulation and reporting – critical areas in current design research. In particularly, the coding and analysis strategies allow successive degrees of detail to be examined whilst maintaining a cohesive structure. Thirdly, there is a significant pragmatic benefit in the reduction of the coding and reporting workload whilst maintaining the contextual grounding and flexibility of the hypothesis specific elements. Finally, the combination of standardisation and flexibility allows effective comparison and triangulation of studies in a standardised and transparent manner – key to developing a wider base of research data within the community.

As highlighted in Table 11 further work is necessary to: identify the significance of various contextual factors and formalise their reporting in design research; develop and validate the links between sample design and the required contextual information; and examination of the significance and extent of experimental effects in the engineering design domain. Further to this, and most critical to this work is the ongoing requirement to validate the foundational method in practice. However, as true validation can only come through multiple applications in numerous contexts and by many different researchers, this is beyond the scope of any one work. As such, it is hoped that by providing the basis for such comparisons over time and across multiple studies the foundational method will ultimately be validated in practice through examination, critique and adoption by the engineering design research community itself.

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Appendix – Code Definitions

Group	Code	Definition
Situation	Individual	No real time interaction with any other individual or group
	Group	Real time interaction with one or more other individuals
	Synchronous	No delays between communications
	Asynchronous	Significant delays (longer than a few seconds) between communications
	Co-located	Working in the same location at the time of an interaction
	Distributed	Working in different locations at the time of an interaction
Environment	Location	The specific location of the participant in their main work site
Focus	Design process stage	The stage at which an interaction is taking place within the associated project – see Hales (1991) for stage definitions
	People	The subject of an interaction includes: personnel, personal, managing people, customers
	Product	The subject of an interaction includes: prototypes, design documents, project management

	Process	The subject of an interaction includes: resources/time allocation, scheduling, stage gate management
Problem solving	Goal setting	Identifying where the design is and where it needs progressing to
	Constraining	Imposing boundaries with requirements and desirables
	Exploring	Discussing possibilities and ideas invoking suggestions
	Solving	Involves searching, gathering, creating, developing solutions
	Evaluating	Judging the quality, value and importance of something
	Decision making	Considering key factors from evaluation and possible compromises to form decisions
	Reflection	Reflecting upon a design decision or process already adopted or occurred
	Debating	Discussing opposing views
Information exchange	Recognising need	Recognising a problem or deficit
	Seeking	Finding information
	Requesting	Direct requests to another party to provide information
	Interpretation	Assigning meaning or value to information
	Validation	Checking the authenticity or value of information
	Informing	Using information to inform one or more people
	Clarifying	Using information specifically to resolve issues or clarity problems
	Confirming	Using information specifically to affirm or confirm a issue or point
Management exchange	Managing	Specifically arranging, directing or instructing with regards to people, product or process
Audiovisual	Audio only	Only using audio input or output
	Visual only	Only using visual inputs or outputs
	Audiovisual	Using both audio and visual inputs or outputs
Documentation	Formal	Provides a specific context and measure with a structure or a focus such that individuals exposed to it may infer the same knowledge from it (Hicks et al. 2002)
	Informal	This encompasses any unstructured information (Hicks et al. 2002)
Physical	Environment	Physical objects not directly related to the design
	Tools	Design tools used with respect to the design (Schon 1984)
	Design representations	Objects related to the specific design under discussion – prototypes, visualisations, mock-ups etc
Type of exchange	Opinion	Giving or receiving opinions: includes evaluation, analysis, expression of feeling or wish
	Orientation	Giving or receiving orientation or scene setting: includes information, repetition, confirmation
	Suggestion	Giving or receiving direction or proposed possibilities: includes direction, possible modes of action
Understanding	Agree/disagree	The participant shows passive acceptance/rejection, understands, concurs, complies/formality, withholds resources
Personal	Antagonism/ solidarity	Giving or receiving support/criticism: increases/decreases others status, gives help or rewards others/asserts or defends self
	Tension/ tension release	The participants jokes, laughs, shows satisfaction/asks for help, withdraws