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Enacted Affordance when Doing Transdisciplinary Engineering

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Abstract. This study of transdisciplinary engineering draws on the concept of affordance with the purpose of bridging the across boundary interactions research and technical interactions research. Affordance, possibilities for actions, is enacted in the relationship between an engineer's experience and artefacts when transforming a perceived indeterminacy into a determinate situation. We use three examples from an ethnographic study to analyse the extent to which perceived indeterminacy influences affordance. Three types of affordances are conceptualised; shared affordance if low perceived indeterminacy, collective affordance if increasing perceived indeterminacy and pragmatic affordance if high indeterminacy. Cues from an "Interface Diagram model" artefact are sufficient to enact shared affordance, thus possibilities for actions across boundaries. Cues from a "Product Architecture model" artefact are adequate to enact collective affordance, thus possibilities for actions across boundaries. The multifarious cues from a "Quality Function Deployment matrix" artefact pave the way for pragmatic affordance, thus a common ground in terms of which possibilities for actions across boundary should be brought to the fore, supressed or even omitted.

Keywords. Affordance, pragmatism, across boundary, technical interactions.

Introduction

Across boundary interactions and clarification of technical interactions among components are pivotal activities when doing transdisciplinary engineering (TE). Across boundary interaction has achieved extensive attention the past two decades [1] as instrumental in transferring, translating or transforming [2] different users' requirements into product and manufacturing specifications [3], [4]. Researchers addressing the technical interactions to fulfil functionality requirements have elaborated pros and cons of using integral versus modular architecture [5] and illustrated the benefits of using design structure matrixes in a standardised way [6].

However, given that TE is challenging [7], some researchers highlight that TE has a sociotechnical nature [8] and thus suggest understanding development as a socio-technical activity [3], [9]. Hence, if aiming at improving our understanding of TE it seems problematic to keep apart the social and technical matters when studying how engineers conduct development activities. This viewpoint is not new; the Science Technology and Society studies have proven that the social and technical matters are co-shaped and fuse into a sociotechnical practice when handling an activity [10], [11]; this paper appreciates the work of Leonardi [12], who draws on the concept of

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imbrication to propose that socio and technical matters are two distinct phenomena that gradually become interlocked in a particular sequence when engineers are handling a development activity.

The concept of affordance - possibilities for actions – sheds light on the cues inviting an engineer to act upon an artefact in a given environment [13] and affordance rejects the social and technical dualism [14], [15]. Some researchers suggest that affordance depends on the individual's cognitive system [16], [17], [18]. However, in contrast to the researchers bringing cognition to the fore, this paper suggests that affordance is enacted when transforming a perceived indeterminacy into a determinate situation, which involves reciprocity between an engineer's embodied experience and artefacts. The transformation of a perceived indeterminacy into determinacy consists of a number of actions [19], [20]; handling perceived indeterminacy is an inquiring process [19].

This research aims at studying affordance when doing TE and to guide the research we ask "*to what extent does perceived indeterminacy influence affordance*".

Three examples from an ethnographic study accomplished by one of the authors makes up the empirical material in this paper; the ethnographic study followed the development and running-in manufacturing of two wind turbine control applications.

The novelty of this research is the use of the affordance-based perspective to bridge two TE streams of research; across boundary interactions and technical interactions. By doing so, the paper's contributions are; a conceptualisation of three types of affordance - shared-, collective- and pragmatic affordance; while shared affordance is enacted in settings characterised by low perceived indeterminacy, collective affordance is crucial if the possibilities for actions are interdependent, but in situations where the possibilities for actions are in conflict pragmatic affordance seems necessary meaning that some possibilities for actions should be prioritised, other supressed or even omitted; we show that engineers having different experience deliberately use laptops, blackboards, IT-systems and various artefacts to enact affordance, yet in some situations lack of crucial information, unusable artefacts or lack of experience hinder the possibilities for actions meaning that affordance should not be taken for granted.

The paper is structured as follows. The next section elaborates the theoretical positioning followed by methodological considerations. Then, the three examples are presented and analysed, and finally the discussion and conclusion are presented.

1. Theory

This section starts with a brief literature overview of the technical- and across boundary interactions. Following this, we present our conceptualisation of affordance and perceived indeterminacy

1.1. Literature overview

Several prescriptive models to handle the technical interactions have seen the light of the day. Some researchers advocate for using a matrix approach. The "Quality Function Deployment" matrix is a useful artefact for both transforming functional requirement into detailed specifications and for identifying a preliminary business model for the sustainable products being developed [21]. Furthermore, the use of the "Design

Structure Matrix" artefact makes it possible to cluster functionality requirements and thereby identify functional elements to be reused in the development of new product platforms [6]. Other researchers strive to create models that are easier to use than the above matrix approaches in an attempt to utilise the visualisation effect of the artefacts. The "Interface diagram" artefact has according to the authors sufficient visual capabilities to decompose a product into sub-systems, modules, components and interfaces [22] and in the same vein by creating and using a "Visual product architecture model" the communication and decision-making during product development will be improved [23].

The above stream of research focusing on the technical interactions acknowledges the importance of across boundary interactions and in general, the visual representation of the artefact (the applied model) is considered as being the facilitator for the across boundary interactions. However, an artefact does not have a deterministic effect meaning that an across boundary interaction does not take place by itself [8]. For instance, an artefact that is too complex might paralyse the practitioners [24] and in some situations the requirements specified in the artefacts are diverging [8], which results in an artefact potentially having undesirable influence on the engineers' experience and judgement and thereby on the across boundary interactions [1]. Thus, rather than having a deterministic effect, the artefact influences the across boundary interactions, meaning that an artefact is only instrumental in the across boundary interactions. In other words, our current understanding of across boundary interactions is still incipient (e.g. [8]).

In the following, we conceptualise our understanding of affordance.

1.2. On the term "affordance"

Gibson's [25] concept of affordance has been applied across multiple research domains to study the reciprocity between human (social) and artefacts (technical). Norman [26] introduces affordance to the design domain and highlights that the human-artefact affordance depends on the human's past experience with using "the thing" (artefact). By doing so, Norman's conceptualisation of perceived affordance departures from Gibson's unconscious actions. In addition to these two seminal contributions, this paper appreciates; Hutchby's [14] "third way" to close the gap between realism and social constructivism; Maier and Fadel's [27] affordance design method as a means to accomplish Design for X development; Gero and Kannengiesser [17] representational affordance indicating that affordances is situational and emerge in the relation between engineers and artefacts; Pucillo and Cascini's [28] viewpoint that artefacts can, in a hierarchical manner, afford four different kinds of actions. Each of the four types of affordances requires different mental faculties, from directly perception to perception drawing on cognitive and emotional faculties; and in the same vein, Leonardi's [12] distinction between different types of affordances and his concept of imbrication suggesting that affordance is sociotechnically enacted (like [15]). Despite appreciating these valuable contributions, the conceptualisation of affordance in this paper is slight different.

Firstly, an engineer's thinking and action is inseparable and situational; it is a "thinking-in-action" process [19] influenced by artefacts [10] and the social interplay with other engineers [29]. It means that technical matters (artefacts) and social matters (social interplay) acquire meaning for the individual engineer and thus gain an influencing role when he/she is handling an indeterminacy. Hence, affordance is enacted when an engineer gradually handles an indeterminacy by conducting a "*controlled transformation of an indeterminate situation into a determinately unified one*" [19, p. 121].

Secondly, engineers have different faculties [19] and commitment for acting [28], [32] and given that applied language differs [29] artefacts such as a drawing might facilitate different understandings when engineers are handling an indeterminacy; i.e., affordance differs among the involved engineers.

Thirdly, inspired by the work of [12], [28], [30] we conceptualise three types of affordance; shared, collective and pragmatic affordance. Shared affordance means that all engineers have the same possibilities for actions. Collective affordance means that the possibilities for actions differ among the involved engineers. Pragmatic affordance means that the possibilities for actions are localised, embedded and invested in a situated practice.

The following section conceptualises perceived indeterminacy.

1.3. Perceived indeterminacy

This paper assumes that perceived indeterminacy is influenced by the type of architecture applied in the product being development and the nature of information being shared across boundaries.

An architecture can be either integral, closed modular or open modular [5], [31]. The integral architecture is characterised by many-to-many technical interactions among the functional and physical elements and thus a great many interfaces to take into account. The closed modular architecture, by contrast, operates with a limited number of customised interfaces and the open modular architecture has standardised one-to-one technical interactions implying very few interfaces to address. Thus, an integral architecture has a higher influence on the perceived indeterminacy compare to the closed and open modular architecture, respectively.

The nature of the information changes throughout the development (e.g. [3]) and in relation to across boundaries interactions some knowledge is immediately understandable, other knowledge requires interpretations or event negotiations among the involved engineers [2], [30], [33]. In other words, the extent of the gap between received information and existing domain-specific knowledge influences the perception of the indeterminacy.

Drawing on the above and the work of Lager [34], this paper operationalises perceived indeterminacy as; Low, if the technical interactions occur via few interfaces and the gap between received information and existing domain-specific knowledge is low; High, if the technical interactions occur via many interfaces and the gap between received information and existing domain-specific knowledge is high.

2. Methodological considerations

The empirical material in this paper draws on examples from an ethnographic research. As for the ethnographic research, the supplying company develops and manufactures control applications to Original Equipment Manufacturers in the wind turbine industry; the supplying company has been in the industry for more than three decades.

Adopting multi-sited ethnography, one of the authors of this paper followed the development including running-in manufacturing of two control applications within and between different practices [35]. The criterion for selecting the two projects draws on [36]. One addresses the supplying company's long-term collaboration with a customer - the two companies have collaborated for nearly three decades, while the other deals with the supplier's collaboration with a new customer. Both projects call for the accomplishment of development activities within daily practices as well as cross-functional and inter-organisational settings and involve the drawing up of functional-, detail-, manufacturing specifications and manufacturing of the physical applications. Due to length limitation of this paper, only three examples from the ethnographic study are included, which introduces a limitation of this study, as daylong "possibilities for actions" are not described, yet these contribute to our understanding.

As for the ethnographic study, the data collection extended over 12 months being divided into two phases. The first phase lasted four months: observations of four meetings and 14 unstructured interviews documented by notes. The second phase lasted eight months; six hours daily observations within open-plan offices/manufacturing areas, three working days a week; observations of 31 cross-functional and 25 inter-organisational meetings, each lasting, on average, 95 minutes; 16 semi-structured and taped interviews. The observations encompassed dialogue, body language and voice, how artefacts, mobile phones, laptops and blackboards were used, the characteristics of the room, whether or not IT systems were functioning, whether or not persons were reachable by mobile phone. Observations were recorded directly in MS-Word documents.

3. Empirical examples

In the following three examples of handling a development activity are presented.

The first example describes an inter-organisational meeting, which takes place in a meeting room at supplier's location. Customer-engineer (C-engineer) uses a laptop to retrieve a 3D drawing from Customer's intranet and presents it. The 3D drawing of the application is displayed from various angles and cover plates are dismantled; he explains verbally and use his hand to make a drawing in the air. Following this, Supplier-engineer's (S-engineer) body language shows a reflection going on and after a while, he asks about cabling interfaces among three breaker panels. Despite an intense dialogue and the use of CAD systems to depict the 3D drawing the engineers were incapable of finding a solution at the time being. Hence, this dialogue stops but another one starts up immediately as C-engineers says "*I can see you have three ampere here.*", then he takes a close look at an electrical diagram just in front of him and after a while his eyes move to the laptop after which his says "*you have three ampere her and the brakes are not included*". S-engineer replies "*yes, it is correct*", which leads C-engineer to suggest "*we have as much as 9 ampere to use, why not increase it to 4.5 ampere*" and S-engineer agrees "*yes, let's do it*".

The second example is an inter-organisational meeting at Customer's location; C-engineers, S-engineers and two consultant companies participate; specialist in mechanical design and specialist within dimensioning of gearboxes, respectively. According to one of the participating S-engineers developing software, the consultant companies "*conduct lots of calculations and simulations concerning load and stress on the components in the wind turbine. In order to carry out these, they need to know how we regulate the wind turbine. For instance, depending on how we pitch the blades in the wind, you will get different forces and vibrations in the components. And as the* *gearbox is normally a problem, you have to minimise these forces and vibrations*". The important dialogues are in general between S-engineers and engineers from the two consultant companies, whereas the various C-engineers responsible for mechanics, gearbox, electricity and hydraulics eagerly notes down. The meeting ends with the C-engineers are assured that all issues are addressed, yet some technical clarifications remain. One of the S-engineer (hardware) tells it in this way "*I went to a meeting yesterday, where these gear people were present and I inquired into the issue and got some information. And now I am going to sit down and describe how gear cooling and the lubrication system can work and I will then [....] describe how I want to control it, and this I will send directly to the* [gear consultant] *and the I will ask them to provide comments*".

The third example takes place in the manufacturing. Despite the application has been a central topic in several inter-organisational meetings, it is the first time the C-engineer sees the physical application. The C-engineer walks around the breaker panel, he stops and then, he dismantles a cover and looks at the three huge cobber bars, which go down from the top of the breaker panel to the maximum circuit breaker. The C-engineer looks carefully at the space between the cobber bars and especially the isolator between these. The C-engineer finds a measuring tape and does some measurements; after a while, he suggests a design change. A S-engineer takes a carpenter's ruler and points at the isolators and emphasises, "*no it is not possible, but what is your concern?*". The C-engineer says, "*I am afraid of short circuits*". This leads to a long dialogue and the use of various sketches, drawing and diagrams; several solutions are proposed, but all proposals are considered inappropriate. After a while, the C-engineer draws a sketch on paper and puts forward an idea, but he still has some doubt "*maybe there are some guidelines for the necessary space?*". Consequently, he places his laptop on the workbench and gains access to technical standards addressing recommended space between cobber bars. This information, combined with a great many measurements of the physical application, drawing up sketches and dialogues, facilitates a sufficient progress of handling this activity. At last, the C-engineer suggests "*if we turn the copper bars 90 degrees and fix them to this part of the frame and enlarge the isolators between each of the copper bars, it fulfils the requirements*". According to the S-engineers, these minor changes of the product specifications entail a huge revision of the physical application including all manufacturing specifications.

4. Framework for studying TE and examples revised

In this section, we propose a framework for studying TE and we analyse "*to what extent does perceived indeterminacy influence affordance*". The framework illustrated in Figure 1 draws on conceptual reflections and the three examples in the preceding sections.

The framework subscribes to the definitions of low/high perceived indeterminacy and the fact that engineers do not demonstrate the same level of commitment when transforming an indeterminacy into a determinate situation. It means that the perception of indeterminacy can differ between involved actors which appears from the figure; it can be low or high for actor A and likewise low or high for actor B. An actor is understood as an engineer or a group of engineers operating within the same "*object world*" [29].

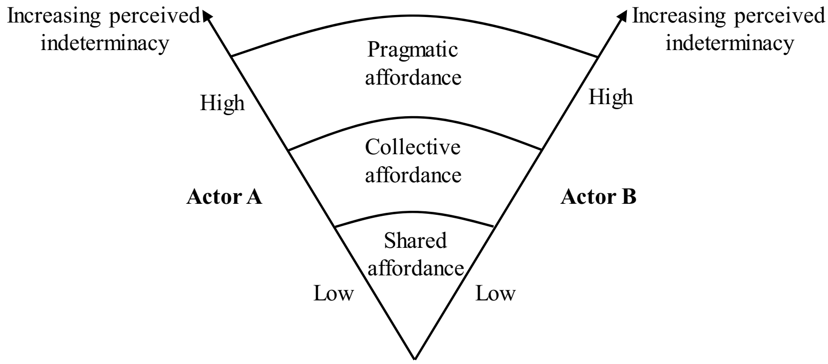

Figure 1. Framework for studying TE.

In the first example addressing the current intensity, the two actors are familiar with the indeterminacy being handled. Only one of twelve electrical diagrams brought along to this inter-organisational meeting is applied indicating that the technical interactions occur via few interfaces. Likewise, certainly both the C-engineer and the S-engineer are highly skilled and the majority of laws with respect to ampere, voltages, ohms, etc. are basic knowledge to them. Despite the engineers know how to handle the situation, they continuously add handmade symbols, sketches and red-and green lines directly on the applied diagram illustrating that affordance is enacted when handling the activity. The example demonstrates that the two engineers quickly gain a common ground for the indeterminacy and that they have the same possibilities for actions when interacting with the artefact(s), thus shared affordance.

The second example shows the importance of facilitating different possibilities for actions among the involved actors. The purpose of handling the activities is to audit the technical interactions among sub-systems as gearbox, hydraulics, mechanical main components and the applications developed by S-engineers; at this sub-system level (see [37]), the interfaces in the wind turbine are customised entailing that the technical interactions occur via a number of interfaces. The example demonstrates that the gap between "received information and existing domains-specific knowledge" differs among the involved engineers and that the S-engineers' use of artefacts to explicate how their applications regulate the wind turbine causes rather different actions; Engineers from the two consultant companies struggle to examine issues related to mechanical stability thus perceiving some indeterminacy; S-engineers realise issues concerning gear cooling and lubrication system resulting in an iteration of the software development; C-engineers eagerly notes down in an attempt to improve their understanding of gearbox, hydraulics, electricity and mechanics interfaces; and finally, C-project manager becomes convinced that all issues are addressed. Hence, collective affordances is important if the actions accomplished by each of the involved engineers' are interdependent.

In the third example, in which the C-engineer sees the physical application for the first time, we witness that the possibilities for actions are localised, embedded and invested in a situated practice. Quickly, the C-engineer identifies a design mistake, which none of the S-engineers have yet recognised. Various drawings, diagrams, the physical application, hand tools, laptop to access different standards and ongoing creation of sketches are necessary and it takes a while to gain a common understanding of the indeterminacy and to identify a solution. While the solution entails minor modifications seen from the C-engineer's perspective, the changes are more sweeping seen from the S-engineers' perspective. This example illustrates that the great many interfaces and the gap between existing and new knowledge cause a problematic situation for the involved engineers. Hence, facing such a situation it is necessary to supress or omit some of the possibilities for actions in order to handle the TE activity.

5. Discussion

The three examples demonstrate that affordance is enacted; for instance, handmade symbols, sketches and red/green lines are added directly on the applied artefacts. Depending on the involved actors' perceived indeterminacy, the possibilities for actions should be either shared, collective or pragmatic. In the shared affordance example, we witness that the actions to handle the indeterminacy in relation to the current intensity in one circuit do only involve one artefact and "Ohm's law" is basic knowledge for the two engineers. Regarding the collective affordance example, the perceived indeterminacy differs among the involved engineers. The S-engineers take the lead and apply laptops and CAD system to depict various drawings and diagrams on the TV screen when auditing the interfaces and obviously the actions being conducted by the involved engineers differ; mainly due to the different groups of engineers have dissimilar area of responsibility and thus facing different indeterminacy, but also due to the facts that engineers have different experience. As for pragmatic affordance, the third example addressing the design changes, we see that the possibilities for actions are characterised by much to and fro meaning that the actions being conducted require some effort. In this situation, affordance is not just related to one artefact, rather various artefacts, hand tools, laptops to access different standards and ongoing creation of sketches are necessary. In addition, we also witness the importance of the involved engineers are capable of utilising and combining their different experience.

The above analyses indicate that both the representation fidelity of the artefact(s), the embodied experience and the social interplay among the involved engineers influence the possibilities for actions. These findings have some similarities to the viewpoints that affordance is the cues inviting an engineer to act upon an artefact [13] and that the characteristics of artefacts should be adapted to the nature of knowledge [30] and the complexity of handling the activity [3]. Accordingly, to enact shared affordance the cues from the "Interface diagram" [22] will facilitate sufficient coordination [3] to identify appropriate actions across boundaries. As for collective affordance, the cues should pave the way for different actions and consequently this paper suggests using the "product architecture model" [23] to facilitate sufficient coaction [3] across boundaries. Regarding pragmatic affordance, the multifarious cues from a "Quality Function Deployment" matrix [21] can pave the way for collaboration [3] and thus a common ground in terms of which possibilities for actions should be brought to the fore, supressed or even omitted.

Revisiting the first example, where the engineers are incapable of clarifying the cabling among three sub-systems, illustrates a situation in which affordance gradually ceases. Despite they are using the laptop to depict electrical diagrams and are switching among different diagrams to follow the complete wiring in all applications, undecided technical issues in other sub-systems of the wind turbine gradually hinder the possibilities for actions. Hence, this paper suggests that affordance should not be taken for granted, which supports Burlamaqui and Dong's [13] viewpoint that affordance is influenced by the transmission of cues between an artefact and the perceiver within a situational context. Yet, our findings show that the involved engineers deliberately apply laptops, blackboards, IT-systems and various artefacts to enable the transmission of cues, but in some situations lack of crucial information, unusable artefacts or lack of experience hinder the possibilities for actions.

6. Conclusion

The purpose of this paper was to study affordance when handling TE activities. Affordance, possibilities for actions, is enacted when transforming an indeterminate situation into a determinate one. The paper conceptualises three types of affordance. While shared affordance is enacted in settings characterised by low perceived indeterminacy, collective affordance is important if the actions to be accomplished are interdependent. Pragmatic affordance means that the possibilities for actions are in conflict; to manage such a situation some possibilities for actions should be prioritised, other supressed or even omitted.

By doing this study, we hope to contribute to a further development of the affordance-based perspective and thereby help conceptualising and using sociotechnical approaches to the study of TE. Our answers to Moser et al. [9] statement are highlighted with bold text in the [] - "*what we produce* [**we produce technical interactions**] *and how we work* [**we work across boundaries**] *combine as a sociotechnical system in which products, processes, and people interact and evolve*. Hence, this study subscribes to the viewpoint that "what we produce" and "how we work" are co-shaped entailing that TE activities are accomplished within sociotechnical practices; affordance, possibilities for actions, is enacted by engineer-artefact interactions and the social interactions among the involved engineers within a sociotechnical practice.

Future work includes in-depth studies of TE work in which varying degrees of indeterminacy occurs. Also, future work includes TE with coping strategies that can be applied to support engineers use of artefacts in situations with shared, collective, and pragmatic affordance.

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