Understanding the Tangible within IS

Completed Research Paper

Reeva Lederman
School of Computing and IS
University of Melbourne
Reeva.lederman@unimelb.edu.au

Paul Beynon-Davies
Cardiff Business School
University of Cardiff
Beynon-daviesp@cardiff.ac.uk

Abstract

This paper proposes the contemporary relevance of a previously unrecognized class of IS, a tangible IS (TIS), which are comprised of tangible (visual/material) artefacts, such as magnetic tokens and physical whiteboards, used within contemporary settings such as hospitals and production settings, to support routine work by multiple actors. We propose several features of TIS and examine why attempts to computerize such systems often fail. By theorizing about how information emerges within TIS we present a novel application of the theory of affordances. We show how acts involving the articulation of tangible artefacts afford acts of communication, which in turn afford the coordination of work actions. We explain in terms of our theorization why an electronic whiteboard, designed to replace the previous TIS within an ICU ward, suffers from a number of 'information' problems. We propose principles for IS design based upon our innovative use of affordance theory.

Keywords: Theory of Affordance; Tangible Systems; IS; Failure; Design

Introduction

This paper tells the story of two IS situated within the intensive care unit (ICU) of a major public hospital in Australia. The first IS was introduced some decades ago based around the manipulation of a physical whiteboard placed in the middle of a busy ward and used to support routine activities involved in admitting and discharging patients. As a 'manual' IS it acted effectively as the primary communication hub for multi-disciplinary teams of healthcare workers for a period of many years. Over time, a range of organizational pressures, such as increased auditing requirements and legislative demands regarding patient privacy, led to this tangible artefact being replaced by a digital computing system interfaced through an electronic whiteboard. However, this digital IS is considered much more cumbersome to use by staff than its earlier 'manual' incarnation. The electronic whiteboard is seen to no longer facilitate many aspects of communication provided by the original system. As a direct consequence of this, a workaround manual whiteboard system has recently been established to reinstate the lost functionality of the previous IS.

We believe that the case described is representative of a wider phenomenon. This paper asks why so many electronic replacements for what we prefer to refer to as tangible IS end up either underutilized or unused. Many such replacements fail to offer improvement over previous IS, some even failing to adequately replace the functionality of the tangible IS they supplanted. Many users of these systems reinstate workarounds using readily available tangible artefacts to attempt to redress perceived problems with these digital IS. This paper seeks to develop a theorization of the tangible in IS which helps answer three related research questions. First, why are tangible IS useful in the first place within certain work settings? Second, why do such systems endure despite increasing attempts at computerization? Third, what can we learn from this class of IS that may help developers better design digital IS for certain ways of organizing work?

The last 50 years have witnessed the digitization of IS across most areas of business and social endeavor. However, there are many interesting examples within the literature of effective systems that could be called IS but which have resisted digitization (Lederman and Johnston, 2007, Lederman and Johnston, 2011).

These systems are clearly IS, despite their non-computerized nature, because the way that they are constructed and used provides the information for routine action sought by their users. Analysis of these systems reveal actors engaged in a variety of activities ranging from air traffic control (Letondal *et al*., 2013), hospital bed management (Wears *et al*., 2006; Pennathur *et al*., 2008; Bateman and Lethbridge, 2014) emergency ambulance control (Wears *et al*., 2007) manufacturing (Anderson, 2010) and software development (Beynon-Davies and Lederman,2017) without recourse to digital computing and communication technology. The introduction of ICT is often associated with opportunities for staff in workplaces to achieve goals, as well as bringing its own set of problems (Lee *et al*, 2014). Research investigating the introduction of information technology into certain situations of routine work has found that new computerized systems may reduce rather than increase the information available to users leading to information deficits (Galsworth, 2005). Studies of air traffic control, where paper flight strips have been replaced, for example, suggest that increased computerization can run the risk of increasing perceptual errors as controllers 'visual channels' become overloaded (Shorrock, 2007). Similarly, computerized hospital whiteboards have been found to reduce situation awareness and users overall understanding of their environment. Physical whiteboards are also found superior in supporting status snap-shots or progress through a plan (Pennathur *et al*, 2008). Because these systems have been shown over decades to be effective in supporting routine work in a large range of settings (Mackay, 1999; Wong and Blandford, 2004; Sehgal, 2010; Hertzum, 2011, Milton, Johnston et al, 2005, Lederman, Johnston and Milton, 2003), it is important to to develop better theorization of their efficacy.

The literature shows that artefacts such as physical whiteboards support activities that are often performed in a routine or reactive manner (Lederman and Johnston, 2008, Lederman and Johnston, 2011, Lederman, Johnston and Milton, 2004, Robey et al, 2013) - allowing, fast and efficient execution of activity. Used in this context, the term 'routine' refers to '*the way skilled actors familiar with situations occurring in their work environment can apprehend the appropriate action response to a given situation without recourse to explicit reasoning or deliberating about the consequences of their actions*'. While previous references to such systems in the literature do not largely attempt to apply theoretical understandings to the operation and persistence of these systems, it is likely to be the effective way in which such artefacts support routine and reactive activity that makes these systems endure. Actors not only find such artefacts easy to use; the tangibility of these artefacts reduces the cognitive load for users in terms of the need to think about what they are going to do next.

In previous work, we referred to the class of IS that employs physical artefacts such as whiteboards as an *Effective Manual System* (Lederman and Johnston, 2011). However, further thinking and observation over time, has made us question both use of the term 'manual' and the use of the term 'effective', because of their normative nature. The use of the term 'manual' in the literature is used typically to refer to any IS prior to computerization. The related use of the term 'effective' tends to suggest that most non-computerized systems are ineffective and that computerization will inevitably transform such systems into something much more effective. Burton-Jones and Grange (2013, p.633) define effective use as '*using a system in a way that help attain the goals for using the system*' and recognize that effective use is applicable to both computerized and non-computerized IS. Our more recent work supports this world-view (Beynon-Davies and Lederman, 2017, Beynon-Davies and Lederman, 2015) and suggests that there exists a group of IS that gain their effectivity from their physicality or tangibility. Such effectivity is frequently diminished in the computerization of such IS.

More recently other authors have described similar system characteristics in work on tangible interfaces and in what is known as tangible computing (Fishkin, 2004; Ishii, 2008). Examples of tangible computing include the case where small figures, representing users of a chat system, are moved around by hand to adjust audio levels; another is a small model of a university campus which displays different views of the campus when rotated (Fishkin, 2004). The systems we studied in previous work bear some similarities to these tangible computing systems because they also couple the emergence of 'information' to the physical inter-action of actors with objects and environments, even though the objects are not digitally enabled. Rather, the information emerges through often tacit rules of operation and their iconic associations with elements within the environment of work - coupled by the constraints embedded both in the physical artefacts themselves and within the physical environment in which they are manipulated (Dourish, 2004). These IS are characterized by the way in which they embed a set of known conventions for action and are designed to work within a physical environment that somehow constrains or limits action choices. These features make it possible to use information that emerges from these systems to act smoothly and routinely,

without conscious decision making. We therefore now use the word *tangible*, rather than manual, because it more fully expresses the experiential nature of artefact use and what artefacts provide for the user. However, it will become apparent, that we are not just dealing with interfaces or computing technologies – we are examining how these artefacts operate at a systemic level. Hence, we rename the systems we previously called effective manual systems and propose a new application of the term tangible, beyond computing and digital interfaces, to the wider concept of a *Tangible IS*.

Thus, the key research question addressed in this paper is: *How do Tangible IS provide information to users?* Our previous work has suggested that the theory of affordances may provide some part of the explanation. In previous work we have argued that (Beynon-Davies and Lederman, 2017) the theory of affordances (Gibson, 1977) is a useful tool in supporting visual management. This is because this theory explains how a skillful actor can act routinely without explicit reasoning and where context, environmental structure and direct perception provide a source of meaning on which to act.

This paper will examine whether this way of thinking about informative action concurs in significant ways with what seems to occur in studied examples of tangible IS. The paper expands on our previous work in five main ways: by identifying and describing the special class of Tangible IS and the lessons that can be learnt from them; by explicitly highlighting the affordance divide, where affordances are perceived as part of a network or layered construct, which is only implicitly addressed in most adoptions of this concept within IS; by positioning of our theorization within the larger IS literature on affordances; by considering the future hybridization of the tangible with the digital; and, providing a table of principles for IS design based on our theorization.

Most approaches to understanding affordances used within the discipline of IS involve what we shall refer to as *first-order affordances* (Gibson, 1977). First-order affordances arise when actors perceive the opportunity for action within structures in the environment (Gibson, 1977). We shall show that most accounts of the concept of affordance utilized within IS explicitly diverge from some of the key presuppositions of the original concept proposed by Gibson. We will also show that many accounts implicitly diverge from the original notion in supposing not one level but a network of affordances and shall argue that this adaptation of the concept is essential for explaining some inherent features of all IS.

In this paper, we attempt to stay as close to the original Gibsonian conception of an affordance as possible but propose the operation of an additional category of affordance - a *second-order affordance* – to explain certain aspects of our observations of tangible IS. The notion of a second-order affordance has been discussed in the psychology literature (Van Leeuwen, 1994) but not previously applied within the IS field. The idea that there are different orders of affordance was first introduced in descriptions of the use of tools. Van Leeuwen (1994) describes the 'ability to hold', as a first-order affordance which expresses the relationship between the user and the tool, but then the relationship between the tool and the target is considered part of a second-order affordance structure. Van Leeuwen's (1994) idea that there can be more direct or less direct relationships in an affordance structure, is extended in this paper to explain the operation of systems which cross multiple domains and the ways in which these domains can be connected to support routine action. This is a new and innovative use of the affordance concept.

The case of a tangible and digital IS within intensive healthcare

Within the current section, we present the case of a tangible IS which we investigated in a previous documented study of an intensive care unit (ICU) at an Australian general hospital. In our study of the ICU multiple sources of evidence were collected over a three-month period, including interview transcripts, video recordings, photographs, notes on observations and descriptions of physical artefacts. Unstructured interviews were conducted in which actors were asked to talk about how they performed activities (see table 1 for interviewee details). Interview questions were broad and encouraged actors to describe freely what the actor was doing and how s/he was doing it. Observations were made during three hour periods at the ICU at different times of the day and evening and were carried out in a non-obtrusive way by just sitting near the whiteboard and 'eavesdropping'. This was done so as not to interrupt the non-deliberative nature of routine activity. Significant artefacts such as the whiteboard, magnets and labels were examined at the ICU and an effort made to find out about the history and development of these artefacts in search of further insight. Photographs were taken of these artefacts, and were examined both in isolation and in their context of use.

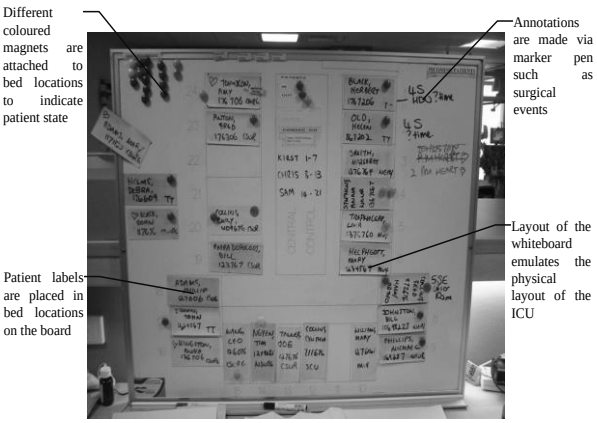

Figure 1. The ICU Whiteboard

Open axial and selective coding were performed on all interview material, memos and operational notes. An initial open coding was performed looking for recurrent phenomena across all data. When data was collected across cases it became apparent that certain concepts were recurring in the data. Axial coding was then used within a theory-driven approach to search for coding categories from among the initial codes and to consider which phenomena related to our developing theorization. Selective coding revealed a number of themes potentially relevant to Gibsons theorization of affordances (Gibson, 1977).

Job Category	Interviewees	Interviewed Once	Interviewed Twice	Interviewed > twice
Head of ICU	1		1	
Chief Nurse	1			1
Nurse Managers	5	3	2	
Registered	20	19	1	
Registrars	8	7	1	
Surgeons	6	6		
Physiotherapists	5	4	1	
Ward Clerks	4	3	1	
Chaplains	3	2	1	

Table 1. Distribution of interviewees in each job category

The methodology yielded the following general description of the way in which the system was used. The tangible IS within the ICU was used to monitor the movement in and out of the ward of ICU patients and supported ancillary activities associated with this movement, such as visits to discharging patients from physiotherapists or chaplains. Staff interviewed told us there was constant unfulfilled demand for beds in all wards and a patient could only be transferred out of ICU if a bed was available elsewhere in the hospital.

The utilization of beds was recorded upon a central artefact, a physical whiteboard (Figure 1) which was positioned in full view of the ward that it depicted, and in such a way that it could be viewed simultaneously by different staff. In an iconic, or skeuomorphic representation (Gross S, et al, 2014), the design depicted bed-shaped rectangles, laid out in the same configuration as the ward. Many kinds of healthcare workers (doctors, nurses, chaplains, physiotherapists) approached this board at frequent intervals throughout the working day. Additionally, the board was positioned at right angles to two ward clerks who processed further data about patients on two computers. The data held on these computers was largely for auditing purposes and did not specifically relate to the bed allocation task. The board contained different informative artefacts, including magnetic labels which had patient names written on them, round colored magnets in red, green, orange and yellow, which indicated the admISion status of patients, and writing produced by erasable and non-erasable colored board markers. Aside from what was written on the magnetized name labels there was a large volume of written material placed around the label that was written up by staff over

the course of the day. This material described relevant activity such as a surgery taking place at a nominated time or the possibility of a bed being available in another ward into which a patient could be discharged.

Users were able to perceive the full situation on the ward with regard to admISions and discharges by a glance at the board in combination with an awareness of what was happening in the ward itself. For example, a cardiac patient might be marked for possible discharge. The patient needed a cardio-thoracic physiotherapist to see them before they were discharged. If the discharging nurse could see by viewing the ward that the physiotherapist was busy with another patient, they knew that patient would not be leaving immediately. Thus, the fact that the board was situated within the ward itself proved vital for carrying out the routine tasks of bed management.

Tacit habits relating to the way the board was used have become established in the workplace and enable staff to act competently and efficiently. A cardio-thoracic physiotherapist, for example, would know through habit that patients whose labels are written in blue are cardiac patients. Consequently, when she viewed the board, she knew that she only had to pay attention to that half of the board with blue labels. This meant that staff. could behave reactively or routinely in response to what was displayed upon the board, once they internalized such habits. These habits or practices support the creation of what Marcus and Silver refer to as functional affordances which can inform action to specific user groups through the relationship of a technical object and given social structures (Marcus and Silver ,2008).

The physical properties of the magnetic labels allowed them to be moved easily from one position to another. Nurses within the ward were often seen picking up and repositioning the labels as they discussed bed movements. Thus, the ability to handle the label in this manner seemed to be significant to staff in being able to help conceptualize the patient situation. In Figure 1, for instance, the label 'Adams, Mary' on the top left-hand side of the board is half on and half off. To those familiar with the system, this conveyed important institutional facts about a possible, not yet firmed up, admISion. As one nurse explained '*At a glance, you can see not just who we've got but all the 'maybe's' in the equation as well*'.

The thematic coding of the interviews with staff produced the following key findings: 1. Work is simplified because action choices are constrained; 2. There are nested physical and social structures; 3. Different actors see potential actions and levels of detail differently. Table 2 provides detailed evidence of how different users responded to the system.

While many effective non-computerized systems involving whiteboards or paper-based schedules are still found in hospitals, they can lead to information management problems (Al-Turki and Bosua, 2011) as they '*leave no permanent trace…. [and] thus cannot provide management information about unit processes and activities*' (Wears *et al.*, 2007). This can be a significant impediment in the modern hospital. Consequently, despite almost universal acceptance of the whiteboard system that we have described among hospital staff, certain concerns relating to data security, auditing and integration led to it being eventually replaced by an electronic whiteboard system.

Within this section we describe how our case setting was revisited, two years after the tangible IS described in the previous section was replaced by a digital IS. This leads us to describe some of the shortcomings of the new digital system. In later sections we ground understanding of such shortcomings in our theorization of tangible IS in terms of two levels of affordances.

In a follow-up to our study, the ICU ward was revisited by one of the researchers and several healthcare workers were interviewed about the use of this new electronic whiteboard. Interviewees consisted of two ward clerks, the director of the ICU and two senior nurses. A smaller number of staff were interviewed than in the original study as we only wanted to interview selected interviewees who had worked under both the tangible and the new digital IS. The interviews were coded by two independent researchers searching for the same themes that had arisen in the original case as well as following an initial open-coding process for other themes that might arise. Interviewees agreed that the workflows and perceived goals of the two systems were largely the same. That is, workers were trying to carry out the same essential functions involved in bed allocation and discharge using both tools.

As with previous research on before and after studies of electronic whiteboard implementations (Hertzum, 2011) it was apparent that there were both gains and losses in the new implementation. It is immediately apparent that the electronic whiteboard displayed in figure 2 bears little resemblance to the original physical whiteboard. There is much more data than on the tangible board written into 24 fields displayed

in horizontal rows across the screen, each row representing a patient on the ward. Our interviews suggested, that some of this data is redundant in supporting the coordination of work on the ward. Certain data items in the patient record are filled in by staff working in other wards for their purposes, but not for the purposes of the ICU. Other data items are left blank, implying their lack of relevance.

Theme	**Interview data**
Theme 1: Work is simplified because action choices are constrained. Explanation: Features of the representational media and ward structure make it obvious to actors how they should act by reducing options.	Doctor: "*It's a diagrammatic representation of the whole unit so I can quickly locate the patient and go have a chat with them.*" Desk Clerk : (example of what happens when choices are not constrained): "*One of registers came in last night looking for Mr: "Where's Mr George? And he didn't pick him up because he wasn't in blue.*"
Theme 2: There are nested physical and social structures Explanation: Actors view actions within a context of activities indicated by the board, the visibility of the ward and social norms. This layering reduces deliberation over each aspect of the system.	Nurse: *"We look at the board, keep an eye on the ward, listen to what doctors are saying and just keep it all in our heads."* Medical consultant: *"I just come (to look at the board) before the ward round for a general impression of how things are.".*
Theme 3: Different actors see potential actions and levels of detail differently Explanation: Features of the representational media and ward structure make it possible for data to stand out for particular actors and not for others.	Chaplain: "*I look for the green magnets because they are people being moved to other wards."* Desk Clerk: *"And that there (pointing to a red heart with AM written beside it) in bed 13 is for the technicians. The rest of us can ignore all that".*

Table 2. Themes that emerged from the data coding and example data

Staff who had worked under both systems said the digital board was more difficult to use than the old whiteboard. In terms of the interface provided to the new electronic system there was a sense that key things of significance now had to be searched for rather than being presented to staff instantly and visually. Much discussion in our interviews revolved around the way in which certain critical alerts were lost. For example, there used to be a magnet for identifying patients with the same name and for palliating patients. Neither of these alerts was set up in the electronic system as a visual alert – these things were instead written on a notes page which needed to be accessed separately on the system. One of the senior nurses commented: '*It's much harder now to work out quickly what you need to know*'.

Within the new digital IS, notification that an alert exists is indicated by the patient number being blacked out. The intention of the system's designers is clearly that staff be required to drill down in such cases to find the alert. However, staff complained that when they did drill down the necessary data was often either mISing or filled with something trivial. A ward clerk, for instance, stated that '*Important alerts like two patients with the same name which used to be easy to see just by looking, now take time to find*'. Two interviewees stated because of the extra overhead in updating the electronic whiteboard it was updated less often and so the data held was less current and reliable.

The original tangible IS was designed to support the work of multi-disciplinary teams of healthcare and associated workers. In contrast, the digital IS seemed to only support the work of nurses within the ICU. Therefore, whereas with the tangible IS the hospital chaplain could see at a glance which patients might require his services, with the digital IS the chaplain now must speak to nurses, when they become available. The tangible IS was also designed to support group action in the sense that 'conferences' were frequently held in front of the board by teams of healthcare workers. The new digital IS encourages individual rather than group action. Staff now must enter data into the system and enquire of the system at a workstation, potentially isolating themselves from fellow workers and ongoing work in this process.

Figure 2. Electronic Whiteboard in the ICU

Most interesting was that deficiencies such as the ones described caused staff to create a workaround system, which utilized a manual whiteboard. While it is possible to type nursing allocations into the electronic board, this requires multiple steps and is rarely done. Instead a small whiteboard has been created which looks very much like the original physical whiteboard in having a picture drawn upon it which mirrors the shape of the ward itself. When questioned about this, staff said that they needed a visual reminder of where beds are placed and that they are responsible for to ensure speedy response to the healthcare needs of patients.

The ubiquity of tangible IS

Systems which use tangible artefacts, such as the physical whiteboard described, are documented in a variety of settings (Arenson *et al*.,1993; Sellen and Harper, 2001; Gladwell, 2002; Swan and Swan, 2009). In studies of air traffic control which use paper flight strips in physical holders, such systems are said to work because of the sheer number of functions such artefacts offer (Hughes *et al*., 1992; Gray, 1993) for activities such as controlling, organizing and prioritizing aircraft landings and take-offs. Mackay et al (1998 p .3) suggest that the paper nature of the flight strips makes it possible for controllers to utilize both '*visual and tactile memory*'. Authors on air-traffic control note the smooth and rapid response rate of controllers (Mackay, Fayard et al, 1998, p.1) using such physical artefacts and suggest that this is part of the reason that these systems are still in use in flight centers around the world (Letondal et al, 2013).

Kanban systems of various forms are another example of enduring paper-based artefacts used for the coordination of 'pull'-based work (Anderson, 2010). The Kanban card is used to control replenishment by workers responding to the sight of an empty spot on the Kanban board. The paper nature of such cards brings flexibility (Schmidt and Simone, 1996) in the sense that the system is easy to change or modify simply by taking cards out where needed, or by an operator simply 'pocketing' a Kanban (Schmidt and Simone, 1996). The tangibility of the cards means that a card can be removed, yet not entirely forgotten about.

Dry-erase (non-electronic) whiteboards used in hospitals, such as in our case example, are a persistent example of enduring tangible IS. These are still commonly found in healthcare settings, despite widespread efforts to replace them with electronic boards (Unluturk, 2014). Electronic whiteboards have been found to be used less than dry-erase boards once introduced and to reduce the users sense of the overall state of the ward (Patterson *et al*, 2010). Problems with electronic boards are partly attributable to difficulties such as being hard to scroll to data, the interface being too small and hard to enlarge and being difficult to adapt to local needs within a department. Users of electronic boards have indicated concerns with highlighting and prioritising patients (Hertzum, 2011), which had been found to be easily facilitated by dry-erase (physical) boards. Physical whiteboards are also said to lessen, '*the effort of co-ordination tasks and responsibilities between distributed collaborators*' (Bardram and Bossen, 2005).

A common feature of these systems mentioned is their visibility and the ways in which they provide visual cues and triggers for their users. In early work on visual systems, Kanban is described as one of many tools which can make a factory work effectively by introducing visual triggers which can be responded to

reactively (Grief, 1989). These devices assist in making these systems effective because they send out highly visible messages that workers are habituated into taking notice of (Galsworth, 2005). Other studies, of how these systems work such as for manual ambulance control, claim that the physical artefact plays a role in helping actors maintain situation awareness. They do this by providing prompts for action and 'status snapshots' (Wong and Blandford, 2004) which result from the way the system is laid out and organized.

It is therefore perhaps not surprising to find that the process of replacing a tangible IS with a digital IS is often fraught with difficulty. For instance, hospital IS implementations which often seek to replace a range of manual systems such as patent record whiteboards and scheduling boards have been particularly beset with adoption ISues. Heeks (2002) described the problems in computerizing health systems and resulting failures as caused by the dominance of what he calls 'hard rationalities' with respect to technology, management and the practice of medicine. These rationalities are seen to ignore cultural values, place financial goals above other system requirements and wrongly prioritise stakeholders.

Other research shows that one important system failure point comes from designers not understanding the features of the system they are replacing (Southon, Sauer and Dampney, 1999). With systems based around hospital whiteboards, for example, there can be assumptions made about the features, such as that the boards' merely record patient names, when in fact such systems have many other subtle and subjective uses. Where clinicians have been reluctant to use new systems in hospitals they have reported that they were '*actually losing functionality*' (Southon, Sauer and Dampney, 1999) by moving to digital systems. Within the large system implementations detailed in such studies, what are seen as minor elements such as whiteboards in individual wards, are often just swept away with the presumption that what they represent is easily converted into a standard data structure in a computerized database table. There is often not a full understanding of the part that such system elements play within routine work.

It is evident from the large amount of literature on IS failure (Beynon-Davies, 2013, Heeks, 2006) that systems are unlikely to be well received by stakeholders if they do not in some way meet expectations. Hence, an IS is unlikely to be regarded a success if it is designed to meet wider organizational policy-related goals rather than considering local, customer or user-serving goals (Mitev, 2000). This was shown clearly in the failed implementation of the Paris railway ticketing system where the focus moved away from individual stations as the basic fare related entity to relationships between stations. As well as evidencing little understanding about where and how ticket purchasing was commonly done by customers, ticketing was designed to support choices which favored a certain political agenda with regards to travel patterns (Mitev, 2000), rather than the natural choices of users.

Berg suggests that what manual and paper based systems do best is to facilitate small-group communication (Berg, 2001). Berg identifies redesigns which remove paper artefacts as creating a failure point where tacit knowledge can be lost, along with '*socio-technical synergies in existing working practices*' (Berg, 2001). Further work also suggests systems fail where they do not take account of the different roles of users (Bartis and Mitev, 2008). Other factors working against the success of new computerized systems include lack of user involvement in the design, misunderstanding of user requirements, improper definitions of roles and responsibilities (Al-Ahmad, *et al*, 2009).

Some of these reasons may help explain the reluctance of many users to relinquish paper and token-based systems which have evolved over time to satisfy important organizational and user goals. Because these systems have been shown over decades to be effective in supporting routine work in a large range of settings (Arenson, Seshadri *et al*., 1988; Gray, 1993; Mackay, 1999; Wong and Blandford, 2004; Wears *et al*., 2006; Sehgal, 2010; Hertzum, 2011), it is important to extend our understanding of how and why they still operate and to develop better theorization of their efficacy.

Theorizing tangible IS

The idea of an affordance was first proposed by Gibson as '*what the environment provides or furnishes*' (Gibson, 1977,1979). He proposed that through the way in which an environment was structured actors could directly perceive possible courses of action. This form of direct perception reduced the need for cognitive processing or translation of the message received. For Gibson, '*Perception, in short, was behaviour*' (Sanders, 1993). In order to take advantage of the structure perceived, actors needed to have certain abilities or effectivities which are '*properties of animals that allow them to make use of affordances*' (Shaw and Turvey, 1982). For instance, a piece of rock of an appropriate size and shape is only sit-able

because we as humans have stereo vision, which allows us to sense such physical objects as having three dimensions. But we are also organisms capable of moving on two legs and as such can effect the act of sitting upon such structures. However, unlike much of the literature on affordances within IS we try to keep as much of Gibson's original intention within our theorization as possible. The only element of the Gibsonian affordance that we reject is the idea that structures are necessarily invariant or non-arbitrary. This leads us to preserve the notion that understanding the effectivities of actors is important to unpacking affordances, but to make the associated observation that many such effectivities relate to behavioral and learned rather than inherited habits acquired by actors. This supports what Marcus and Silver (2008) observed, where the opportunity for action provided by the functional affordances of artefacts, can be learnt or acculturated.

As well as keeping the idea that structures may be perceived directly without conscious processing by actors we also adopt the notion of an affordance as completed action, which is a position not well-represented in the IS literature (Lanamaki *et al*, 2016) but which we think does better justice both to the original conception of Gibson and to explaining some of the efficacy of a tangible IS. Nevertheless, although we try to work with as pure a conception of an affordance as possible, we do find a need to extend this conception in certain ways to adequately theorize about how tangible IS work. In fact, we believe that this extension is a necessary but normally implicit consequence of all attempts to explain the workings of any class of IS in terms of affordances. Gibson's original notion of an affordance makes it difficult to apply to the use of physical artefacts within tangible IS but also to digital artefacts within contemporary IT systems. This is because the conception of an affordance relies upon direct perception of cues provided by structures, which stimulates action in relation solely to such structures. Hence, we perceive the flat planes of a physical structure as sit-on-able – meaning that the affordances of this structure (its potential to enable the act of sitting) clearly relate to transformations involving the structure, and nothing else but the structure.

However, the idea of direct perception of an affordance creates a problem for the case of a Tangible IS. In these systems actors perceive physical artefacts in one work domain which are typically used as cues or triggers to further action in another context or domain. So, for example actors in the ICU perceive the whiteboard and its associated artefacts and know how to act in the ward. This is contrary to the traditional idea of affordances where direct perception of an artefact triggers an action to do with that artefact alone.

To fill this explanatory gap, we propose the idea of first and second order affordances which we have previously discussed briefly in (Beynon-Davies and Lederman, 2017) in relation to visual management. In this theorization we build upon the work of Schmidt and Simone, who refer to two domains of action which mirror what we see in TIS. This idea of two domains hints at the idea of what we shall call a second-order affordance to overcome the conceptual limitations of affordances in situations such as those described above. According to their theorization, work such as the manipulation of flight strips is articulation work whereas the work that goes on in the control of air traffic itself is coordination work. Their view is that the artefacts used in articulation work represent a set of protocols and procedures which are objectified in the artefact. That is, to put it in Gibsonian terms, an actor uses the artefact in his/her articulation work but perceives action opportunities in the artefact relevant to the domain of instrumental work. Schmidt and Simone propose '*a crucial relationship between the work (field of work) and the artefact (belonging to the articulation work) that represents a set of procedures and conventions*' (Schmidt et al, 1996, p. 166). We can see both the distinction and the connection between these two domains of action and that the articulation work somehow contains or reflects the procedures and protocols (in the domain of work) that it makes perceivable. Schmidt and Simone do not fully answer, however, how this 'crucial relationship' works. Schmidt and Simone's discussion of articulation work does not solve the problem of how environmental structure is directly perceived as offering the potential for action in a domain beyond that structure. Is the type of support for action using artefacts proposed by Schmidt and Simone the same use of affordances for unmediated action that Gibson proposes?

At first glance, the idea of second-order affordances is attractive to describe the support provided for this type of action. However, it raises a whole series of questions about how first-order and second-order affordances relate. Our interpretation is that this relationship relies on the notion of convention. Lewis (2002) describes a convention as '*a regularity evident in the behaviour of a set of actors*' and suggests that it serves a key function for such actors. That is, it solves coordination problems. These problems arise when actors have a common goal which needs to be achieved through some joint, coordinated action. Actors within a tangible IS, such as the ICU whiteboard system, learn and utilize conventions between actions associated with the manipulation of tangible artefacts in the articulation domain and structures of

coordinated action in the work domain. However, there are certain questions that remain unanswered in this conceptualization. For instance, what are such conventions and how do they work? Also, how does this theorization help account for coordinated performance of multiple actors? In other words, how does a first-order affordance utilized by one actor in the articulation domain trigger a second-order affordance utilized by a different actor in the work domain?

To explain the gap between first and second order affordances we propose a third domain of action which connects the articulation and coordination domains. This intervening layer of action allows us to explain how action is coordinated between multiple actors. In previous work (Beynon-Davies, 2016, we have found it useful to regard manipulation of data structures in the articulation domain as serving various forms of 'speech act' (Searle, 1970) in what we refer to as the communication domain. In other words, each manipulation of a tangible artefact (such as a magnet on the ICU whiteboard) is likely to trigger one or more informative actions, which fundamentally involve communicative conventions relating transformations in the articulation domain with transformations in the coordination domain.

We see evidence of a similar extension of affordance theory to adequately account for informative situations in the work of Burton-Jones and Grange (2013) and Burton-Jones and Volkoff (2017). Burton-Jones and Grange (2013) set up the idea that effective use of IT is derived from not a single but a network of affordances with some benefits being derived from affordances as more immediate and some more distal, akin to the idea of first and second order affordances we propose. This idea suggests that affordances are best understood as operating within a network in support of effective use.

Making sense of the ICU case

Figure 3 is an attempt to unpack or make sense of the ICU case in terms of our theorization of a tangible IS. In this figure, which only covers part of the system of action evident in the ICU, we see a depiction of three domains of action where first and second-order affordances connect the articulation and coordination domains through a communication layer. This communication layer effectively 'translates' the activity expressed in the articulation work (on the whiteboard) into activity that can be carried out within the coordination domain (with patients and beds).

Starting at the bottom left corner of the figure we see two acts of articulation illustrated where a physical structure, namely a patient label, has been created and is placed upon a position on the whiteboard. Conventionally and as conceived in the dominant literature (Wand and Weber, 1990; 1995) a data structure such as this label is viewed purely as a technological artefact. Data structures are taken to represent propositions about 'things' such as patients in some institutional reality, which is assumed to be observer-independent, meaning that it is the same for all actors. Hence, these acts of articulation which change the state of data structures are meant to directly correspond to the state of some real-world thing within some institutional reality. We take an alternative position and propose that data structures such as the patient label do not correspond to or re-present institutional things, they serve to constitute or bring into existence such institutional things. Data structures help constitute institutional reality through their positioning as communicative acts. The creation of a new patient label acts as an intention in the communication domain. It declares that a new patient needs to be admitted to the hospital ward. The placement of this artefact on the whiteboard itself also communicates some intention: namely that this patient is pending admISion to a staff member viewing the board. These two acts of communication trigger a set of coordinated actions around commencement of patient admISion that we see depicted in the top row of the illustration.

In the third cell of the articulation pattern, the patient label is moved onto a bed cell upon the whiteboard and a red magnet added. This placement of label and associated magnet communicates the intention (through habits acquired by actors working in this domain) that a patient is incoming. This communicative action leads to action in the work domain, the actual admitting procedure. In the fourth cell of the articulation pattern, an orange magnet is now added to an existing patient/bed label upon the whiteboard. Within the communication domain this denotes a possible discharge to staff which prompts preparation for discharge activities within the coordination domain. In the fifth cell of the articulation pattern the magnet is changed to green. This signals to staff that the discharge is definite and needs to be undertaken immediately. In the final cell of the articulation pattern the patient label is removed entirely from the whiteboard. This declares to staff that a discharge is happening and that the relevant bed is now available for a pending patient.

There is a tendency in much of the literature which utilizes affordances within IS to assume that conscious decision-making interposes between a structure, perception and completed action or between different layers in a network of affordances. March (1994) refers to such conscious decision-making as a *logic of consequences* in which choice is equated with conscious and rational planning of action by actors as means to achieve established ends. We believe there is some merit in adopting a more Gibsonian view of the relationship between the affordances of structures and completed action which follows a *logic of appropriateness* rather than consequences. In a logic of appropriateness choice is situated and largely unconscious action. Situated choice means that the responses of actors to situations are accomplished using direct perception of structures in the environment together with tacit knowledge (Polanyi, 1962) of appropriate response embedded in the habits or effectivities of the actor. This means that when a nurse perceives the positioning of a magnetic token of a certain color upon the whiteboard she does need to spend time interpreting this structure and deciding consciously what to do next in relation to this structure. The existence of the structure acts as a direct cue to immediate and appropriate action on the part of the nurse.It is evident from our before and after study that both first and second-order affordances important to this way of organizing bed management within intensive care were accommodated in a rather cumbersome manner into the new digital IS. As we have seen, in terms of first-order affordances, individual articulations of the physical whiteboard served to communicate both content and intent to multi-disciplinary teams of healthcare workers. The selection of certain colored tokens and their positioning on designated parts of the whiteboard served to afford certain communicative actions to multiple actors sometimes working across different shifts such as declaring a patient for admISion, admitting a patient and indicating the readiness of a patient for discharge from the hospital ward.

In the new digital IS, an individual articulates an electronic patient record rather than a tangible token to make sense of which patients are pending admISion, have been admitted and occupying which beds as well as their current state of health. Such articulation typically involves an individual nurse undertaking several actions with the structures of the interface to 'drill down' into the patient record. But certain of the original first-order affordances were also lost in the new system. For instance, the presence of a yellow magnet next to a patient label afforded to all actors the assertion that the relevant patient was palliating. In the new system, whether a patient is palliating is written on a notes page which needs to be accessed separately from the main patient record in a series of articulations with the user interface.

Burton-Jones and Grange (2013) define the effective use of IS in terms of whether using such a system increases the achievement of system goals. For us, the goal of articulating data structures lies in effective communication, and the goal of acts of communication lies in effective coordination of activity. Our study suggests that in such terms the new digital system is less effective than the TIS it replaced.

Future Hybridisation of the Tangible and the Digital

It could be argued that certain deficiencies of effective use relating to the translation of first-order affordances into the new digital system are merely the result of poor IT systems design and that it is perfectly possible to incorporate all necessary first and second-order affordances evident in the original tangible IS into the new digital IS. But this ignores certain features of the tangible which are difficult to reproduce in current digital technologies. Galsworth believes that the translation of the tangible into the digital frequently produces what she refers to as 'information deficits' in situations of routine and reactive work (Galsworth, 2005). She believes that these types of deficits, which she refers to as 'location' or 'specification' deficits occur when workers do not know how to do something, when something is required or how many or how much of something is required.

The introduction of the new digital IS introduced several information deficits into the work situation of the ICU which have reduced the effectiveness of the IS. Acts of articulation situated around the patient record have become individual acts rather than collaborative acts of a team. Individual acts of articulating the electronic patient record, such as finding the appropriate status of a patient, have also become time-consuming and often frustrating for its users. This serves to dis-locate acts of articulation from acts of coordinated, ongoing work. Both location and specification deficits are created because both the digital interface and the way in which data is structured within the system interrupts the situated nature of choice. Data is not immediately available and is frequently incomplete. This leaves nurses unable to respond routinely and as a natural consequence immediately and seamlessly to matters of ongoing healthcare on the ward. We observe that the affordances evident in the articulation of tangible structures seem especially

good at enabling the coordination of work of a certain kind, namely routine work undertaken by small groups of actors in which actors need to react immediately and seamlessly to situations. We have suggested in our theorization that this demands a way of organizing that employs a logic of appropriateness rather than a logic of consequences (March, 1994). So what practical implication does this have for IS design?

We suggest that progress can be made in the development of tangible interfaces to digital systems which may offer a way of developing a 'hybrid' system which not only does full justice to the network of affordances evident within TIS but facilitates in a seamless manner the goals of actors in achieving rapid and routine action. Such a system can also build effective traces of institutional facts for contrasting purposes such as auditing and regulation. Suppose an interface such as that illustrated in figure 4 becomes possible. This tangible interface emulates many of the features of the original tangible whiteboard within the ICU in that rather than data being entered via a keyboard, physical tokens are moved onto or off the interface 'surface'. A patient token first becomes inscribed with a patient name and number to indicate that a given patient is awaiting admISion to the ICU. Medical staff then tap on this token or perhaps place it in a read position on the 'surface' to access further details and decide on this basis the priority of admISion by placing the chosen patient token(s) at a pending position upon the 'surface'. To admit a pending patient, the patient token needs to be placed in an unoccupied bed on the 'surface'. Moving a 'patient' token onto an area of the surface in this manner would not only signal to all other actors within the ICU, it would create a digital trace of the current bed allocation of the patient. Also, placing a token of a certain color on the 'face' of a designated patient not only signals a change of patient state to the actors of the ICU, it enters a digital trace which records this change to their current classification.

While there are movements that suggest that there are qualities in digital design that make this type of skeuomorphism or mirroring of the previous analog artefacts unnecessary (Gross et al, 2014), there is also strong support in Tangible computing for the continued use of meaningful physical phenomenon (Robles and Wiberg, 2010). In professions such as radiography, practitioners learn to read relevant physical artefacts, as do many workers in manufacturing environments, which take particular acculturated forms. It is possible that the capabilities of new screen technologies available in the digital environment will create new affordances. Whether these affordances will remove the need for users to be reminded of previous analog forms is a debate that will continue.

Conclusion

Much of the literature on the replacement of tangible IS with digital IS, as well as our own previous case study, is a story of work being slowed down and time spent navigating the new artefact rather than completing the work required. Thus, new ways of approaching the relationship between tangible and digital IS are needed. To avoid the failure experienced in replacing the digital with the tangible we need to understand the value that TIS provide to routine and reactive work. Thus, our most significant contribution in this paper is in identifying the need to move past thinking about whether old or new technology is better but rather to offer a deeper understanding of the nature of IS which will allow us to put forward an informed opinion on the effectiveness of any system design. We believe that our theorization steps in this direction.

This paper makes three further contributions to the IS literature. Firstly, it establishes the class of TIS as a discrete class of IS with certain features that include the importance of materiality, the temporality of artefacts, the place of physical artefacts within their wider environment, the performativity of artefacts and the importance of the tangible for situated choice. These features help explain why TIS still endure within contemporary work settings despite increasing application of digital computing systems. This is because of the ways in which they are so effective in supporting certain forms of routine and reactive work.

Secondly, this paper has applied the theory of affordances to theorize about how tangible IS work. However, our application of affordance theory leads us to identify an inherent 'affordance divide', where we observe multiple layers of affordances, in relation to its applicability to IS. The affordance divide can only be properly bridged by an explicit recognition of this layering or network of affordances. To do this we posit the existence of both first and second order affordances operating across three coupled domains of action. Our work shows how affordances can be evident and support activity beyond the immediate tangible structures encountered. The analysis shows how work can be performed across multiple domains with tangible informative artefacts such as whiteboards and extends the work of Schmidt and Simone (1996) to

include a layer of communicative conventions. This communicative domain is what supports the coordinated activities of multiple system users.

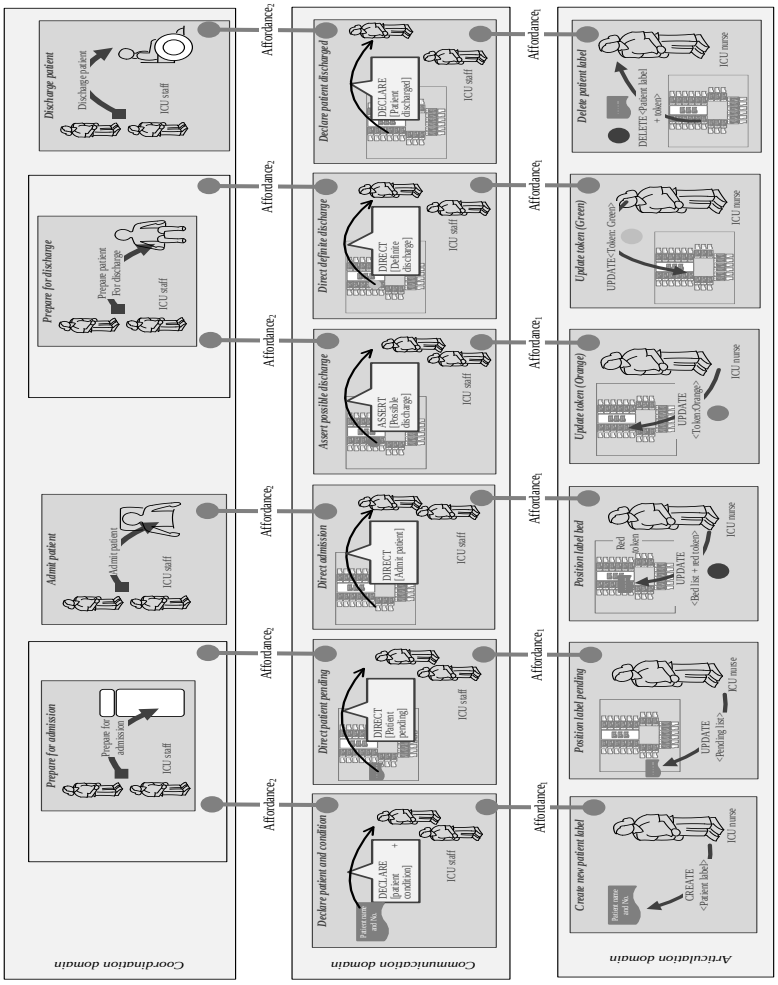

Figure 3. Three domains of the tangible IS within the ICU

In considering how our work informs practice in this respect we need to look to the advice of Meyer *et al* (2013) '*to inventorize organizational practices which are in whole or in part, performed by means of visual … forms of discourse*'. This means that in the analysis of such systems we need to document and understand the ways in which tangible artefacts provide the visual and haptic cues which support coordinated work. Designers also need to understand the role of artefacts such as data structures as key actors in such systems which play a critical role in the coordination of action by multiple actors across space and time. This idea supports suggestions that affordances need to be taken beyond the individual level of analysis by considering how physical artefacts can support teams and organizational units (Robey et al, 2013). While the Internet of Things is promoting a move whereby the interaction and control of tangible objects such as central heating is being done at a distance through digital rather than tangible interfaces, most applications currently facilitate interaction through a single human actor and a single tangible object (Guo et al, 2013). It may be difficult to facilitate team interactions with a complex of objects through existing digital interfaces without rethinking the basis of their design. Thus, thirdly, we have inferred from our work certain lessons for the design of the wider class of IS, which includes digital IS (see Table 3).

The structure of affordances evident in the TIS described in this paper have, to a large extent, evolved through a process of bricolage (Ciborra, 2002). Where affordances have been designed, it is often without significant reference to why or how they make these systems effective. This paper highlights how system implementations that aim to support routine action should be actively planned to incorporate the

communicative conventions that exist in evolved tangible systems. It contributes further by suggesting that IS designers need to consider the role of affordances in *whole systems,* not just interfaces or artefacts, and how information is accomplished across the multiple action domains of such systems.

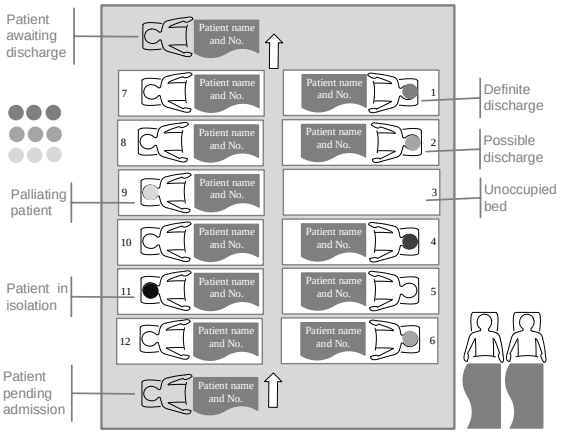

Figure 4. A tangible/digital interface for the ICU

We take it as a general trend that computers and computation in general is gradually moving from the foreground into the background of human activity. This trend has been discussed in various literatures including that which refers to tangible computing (Dourish, 2004), tangible user interfaces (Ishii, 2008), tangible (embodied) interaction (Baskinger and Gross, 2010), pervasive computing (Satyanarayanan, 2001), the internet of things (Atzori, Iera and Morabito, 2010) and ubiquitous computing (Weiser, 1991). This diverse literature suggests that computation will become a pervasive and embedded part of our everyday interaction with tangible artefacts. It further suggests that the design of our interaction with digital computing and communications systems will gradually need to change to accommodate this increased focus on the 'tangible' (Dourish, 2004; Ishii,2008) express this as bridging '*a great divide between the worlds of bits and atoms*'. Through this process, Weiser's (1991) vision of pushing computers into the background and making them invisible will become reality.

Our work highlights the response to the tangible within routine and reactive work that future IS designers ignore at their peril. The effectiveness of the tangible informative artefact within routine work allied to the increasing pressure to address the tangible within computation and human-computer interaction suggests to us the need to explore synergies between tangible IS and tangible computing. There is value in marrying the articulation of physical objects (such as tokens on whiteboards) with digital traces that assemble digital records. In this way, the affordances of the digital record can augment rather than supplant the affordances of the tangible informative artefact. In further work we intend to explore how the theorization described in the current paper might be used as a design theory for such hybrid systems of the tangible.

	Principle	**Description**	**Consequence**
1.	Performativity of informative artefacts	Informative artefacts can only be made sense of as key actors within some wider pattern of action.	Artefacts only become informative within the context of certain situated ways of organizing.
2.	Coupling of three layers of action	Any IS must be made sense of in terms of the coupling of articulation, communication and coordination.	It is impossible to understand any of these three domains of action independently of others.
3.	First-order affordances	To analyse/design any IS effectively demands focus on the opportunities for communicative action afforded by the articulation of artefacts.	The articulation of artefacts is a necessary but not a sufficient condition for the presence of information.
4.	Second-order affordances	To design any IS also demands focus on the opportunities for coordination afforded by communicative action.	The communication of content and intent is a necessary but not a sufficient condition for effective, coordinated action.

5.	Effectiveness of IS	The effectiveness of any given IS can only be understood in terms of principles 1 to 4.	Judgements as to the effectiveness of some IS design can only be formulated in terms of the coupling of action through first and second-order affordances.

Table 3. Orienting principles for IS design based upon our research

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