Affordances, constraints and information flows as 'leverage points' in design for sustainable behaviour

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Abstract

Two of Donella Meadows' 'leverage points' for intervening in systems (1999) seem particularly pertinent to design for sustainable behaviour, in the sense that designers may have the scope to implement them in (re-)designing everyday products and services. The 'rules of the system'—interpreted here to refer to affordances and constraints—and the structure of information flows both offer a range of opportunities for design interventions to influence behaviour change, and in this paper, some of the implications and possibilities are discussed with reference to parallel concepts from within design, HCI and relevant areas of psychology.

1 Meadows' Leverage Points

In common with many areas of interaction design, design for sustainable behaviour (e.g. Wever et al, 2008; Lilley, 2009; Lidman and Renström, 2011; Zachrisson and Boks, 2012) may benefit from the application of a 'systems' perspective to understand better the potentially complex interplay between technology and human behaviour.

One systems perspective which might be relevant is Donella Meadows' concept of 'leverage points', intended to be generally applicable to complex, non-linear systems, though originally developed in the context of systems modelling for world trade negotiations. As presented in the paper 'Leverage Points: Places to intervene in a system' (Meadows, 1999) and the posthumously published *Thinking in Systems* (Meadows, 2009), these are a list of 'places to intervene in a system', ranked in tentative increasing order of effectiveness:

PLACES TO INTERVENE IN A SYSTEM

(in increasing order of effectiveness)

Adapted from Meadows (1999)

12. Constants, parameters, numbers (such as subsidies, taxes, standards)

11. The sizes of buffers and other stabilising stocks, relative to their flows

10. The structure of material stocks and flows (such as transport networks, population age structures)

9. The lengths of delays, relative to the rate of system change

8. The strength of negative feedback loops, relative to the impacts they are trying to correct against

7. The gain around driving positive feedback loops

6. The structure of information flows (who does and does not have access to what kinds of information)

5. The rules of the system (such as incentives, punishments, constraints)

4. The power to add, change, evolve, or self-organise system structure

3. The goals of the system

2. The mindset or paradigm out of which the system—its goals, structure, rules, delays, parameters—arises

1. The power to transcend paradigms

Humans are part of the system just as much as technology and political structures. Hence there is no single leverage point dealing with 'human behaviour'—human decisions, abilities and reactions can be inherent to each of the leverage points, and designers (if they have the opportunity) could address any of the leverage points. However, it is apparent that many (not all) designed interventions which specifically aim to influence user behaviour are concentrated on leverage points 6, 5 and 4: these are the aspects which designers are especially well-placed to tackle through changes to the design of everyday products, services and environments:

- 6: The *structure of information flows* is easily addressable through design: it mainly comprises different kinds of feedback and presentations of antecedent information.

- 5: The *rules of the system* can perhaps best be framed from a design perspective as being about designing in actual affordances and constraints on behaviour (and perhaps also rules for 'reward' and 'punishment').

- 4: The *power to add, change, evolve, or self-organise system structure* could be seen in design terms as being related to *adaptive systems*, i.e. systems which can perhaps adapt the information flows and affordances or constraints present, based on users' behaviour and the performance or context of the system's use.[1]

The 'design for sustainable behaviour' use of these leverage points is often, in practice, a combination of one or more of them—e.g., depending on the context, rewards or punishments could be seen as a kind of feedback, and indeed for a user to be aware of the affordances, constraints and rules that exist, there must be an information flow going on. Thus these categories are not a mutually exclusive definition of possible strategies for intervention, but a way of framing some possible leverage points. Table 1 breaks down these three leverage points into some possible tentative sub-categories pertinent to design for sustainable behaviour. The author has previously employed these categories as a way of assessing the diversity of concepts generated by participants in workshops using the Design with Intent toolkit (Lockton et al 2010a, 2010b).

[1]There are parallels here with elements of models proposed by Wever et al (2008) and Lilley et al (2006).

Table 1: Some possible sub-categories of leverage points 6, 5 and 4

	LEVERAGE POINT	POSSIBLE SUB-CATEGORIES		EXAMPLES
6	Information flows	Antecedent information	6.1	"This car can achieve up to 60 mpg"
		Antecedent information with recommendation	6.2	"This car can achieve up to 60 mpg if you drive it carefully, so please do so"
		Simple feedback	6.3	"You have achieved 48 mpg today"
		Comparative feedback	6.4	"You have achieved 48 mpg today, which is better than the average of 32 mpg"
		Feedforward	6.5	"If you drive more carefully, you should be able to achieve 55 mpg tomorrow"
5	Affordances, constraints & rules	Actual user-level affordances & constraints	5.1	The car affords economical use if driven carefully
		Perceived user-level affordances & constraints	5.2	The driver believes that the car affords economical use if driven carefully
		Built-in system structure & limits	5.3	There is an upper limit on the mpg the car can return even if driven carefully
		Incentives & rewards	5.4	Saving fuel will save the driver money
		Punishments	5.5	Wasting fuel will cost the driver more money
4	Adaptive systems	Adaptive variants of all the above, where possible		

This paper aims to explore some of the implications for designers of, in particular, points 5 and 6—affordances and constraints, and information flows—in the context of influencing more sustainable user behaviour. Subcategories 5.4 and 5.5, dealing with incentives, rewards and punishments, will not be considered in this paper.

2 The rules of the system: affordances and constraints

This section will explore aspects of how behaviour can be influenced through the design of the 'rules of the system'—affordances and constraints, the latter also via related ideas such as forcing functions and *poka-yoke*. Employing affordances and constraints in design is really about deliberately *making things easier or harder*.

While the focus here is on extracting implications applicable to influencing more sustainable behaviour, the ideas are applicable across many fields relating to understanding and influencing behaviour.

2.1 Classifying affordances

"The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill. The verb *to afford* is found in the dictionary, but the noun *affordance* is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment."

James J. Gibson, *The Ecological Approach to Visual Perception*, 1979, p.127 of 1985 edition

Affordances are a fundamental concept in interaction design, popularised in a design context primarily by the impact of Norman's (1988) *The Psychology of Everyday Things* (later republished as *The Design of Everyday Things*). As evinced by the above quote, the concept draws on Gibson's (1979) work in ecological psychology and perception; it has a 'life' outside of design.

In Norman's 1988 definition (p.9), affordances are "the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used", but much of the book concentrates on affordances as being something like 'the function or capability that is perceived by the user', focusing primarily on users' perceptions of the affordances available to them, and how to improve product and interface usability by understanding this aspect of design.

As many have noted (e.g. Flach, 1995; McGrenere & Ho, 2000), Norman's treatment of affordances, or at least the way the concept was adopted by HCI and interaction design, diverges somewhat from Gibson's original concept, which was that affordances existed whether or not they were perceived correctly by an animal in its environment—as Zaff (1995, p.240) puts it, "[t]he individual's continued existence may depend on an ability to detect the available affordances, but the existence of those affordances cannot be said to depend on their felicitous detection". In Gibsonian terms, "a hard, flat, narrow surface may afford walking for me but not for a rhinoceros, and a horizontal surface at the height of my knees may afford sitting for me, but not for a small child" (Warren, 1995, p.211).

2.1.1 Perception

Norman (1999) recognises the difference and suggests that what matters in design is really *perceived* affordance—whether a user perceives and understands, correctly, what actions are possible or not. A ubiquitous example of the power of (perceived) affordances is the use of handles or plates on doors to signal whether they should be pulled or pushed; the frequent passing frustrations of visitors to unfamiliar buildings on finding that their intuitions are incorrect, and a door whose handle appears to say "pull me" actually requires the handle to be pushed, demonstrate how deeply rooted and influential affordances can be in shaping our everyday behaviour. Krippendorff (2006, p.112) suggests that perceived affordances are "the meanings of artefacts in use... a unit of perceptual fit". Some users will perceive different affordances to others—inventive or apparently spontaneous perceptions of opportunities for new behaviours in their environment—powerfully illustrated by Fulton Suri and IDEO (2005) and Brandes and Erlhoff (2006) who have compiled collections of images of objects being used in ways their designers would not have expected.

Gaver (1991) offers a useful 2×2 matrix (Figure 1) separating the existence of affordances from the information available about them, leading to the four categories of *perceptible* (correctly perceived) affordances, *false* affordances, *hidden* affordances and 'correct rejection' (i.e. no affordance present, and none perceived). Each of the categories potentially has some effect on behaviour: carefully determining the affordances available for users to perceive can be part of a strategic use of design to influence behaviour (e.g. Duffy and Verges' (2009) work with different shapes of aperture on recycling bins), while deliberately false affordances (e.g. 'dummy' thermostats: Sandberg, 2003) can also be used to influence behaviour. Hiding an affordance (perhaps from certain users), making it more difficult to access or doing away with it entirely can also be seen as strategic ways of influencing behaviour. Indeed, it is clear that—whether or not seen as being about 'behaviour change'—many design approaches involve the planning and strategic manipulation of the affordances (including perceived affordances) and constraints of a system. That is, the actions or functions which are offered or presented to users (or which they perceive are available to them) and the constraints or limits on their behaviour provided by the system. Constraints are covered in section 2.3.3.

The manner in which the affordances of a system are presented to users, and which possible actions are made more prominent—including aspects such as the choice of *defaults*—will have an impact on the choices users make: in the environmental field, a common example is the increasing adoption of 'economy' 30° or 40°C wash cycles on domestic washing machines.

Gibson focused mainly on visual perception, but later work, such as Gaver's (1991) discussion of *tactile* affordances (feeling how sharp a knife is allows us to perceive whether it has the affordance of slicing a tomato) and Stanton and Edworthy's (1998) research on *auditory* affordances in medical environments, demonstrates a broader range of senses in which perceived affordances can be considered. Assuming that a system is not designed intentionally to have false or hidden affordances to trick or exclude users, in choice terms, a user can only *choose* options which he or she perceives have the affordance of being chosen—i.e. correctly perceived affordances.

2.1.2 Affordances and choice architecture

With the publication of Thaler and Sunstein's (2008) bestseller *Nudge*, the term *choice architecture* has entered political discourse. Politicians (e.g. Osborne, 2008) can now recognise themselves—or journalists can cast them—as choice architects, alongside decision-makers in every field from estate agents to party planners, health authorities to shopping centre developers. Essentially, everyone who is involved in organising how some set of options or choices is presented to other people is necessarily influencing decision-making behaviour, whether intentionally or otherwise. Design theorists (e.g. Buchanan, 1985; Redstrom, 2006) have noted this previously, of course, as have—explicitly or otherwise—a generation of interaction designers deciding which features should be enabled by default, which should be hidden away on an 'Advanced' tab, and so on.

There are clear parallels with the concept of (perceived) affordances: choice architecture is about deciding *which choices to make available (or not)* to the user. In the sense of Heinz von Foerster's ethical imperative "Always act in ways that increase choice" (Ray, 2005), the role of a choice architect in 'editing' choices for users has the potential to be problematic; similar debates have occurred in the persuasive technology community (e.g. Berdichevsky & Neuenschwander, 1999) and in design for sustainable behaviour (Pettersen & Boks, 2008).

It might be considered that hidden affordances are those which, while they are possible, have been edited out of the choices available to us by the 'choice architect' for some reason. For example, Starbucks' 'short' cappuccino, while theoretically available, is intentionally not

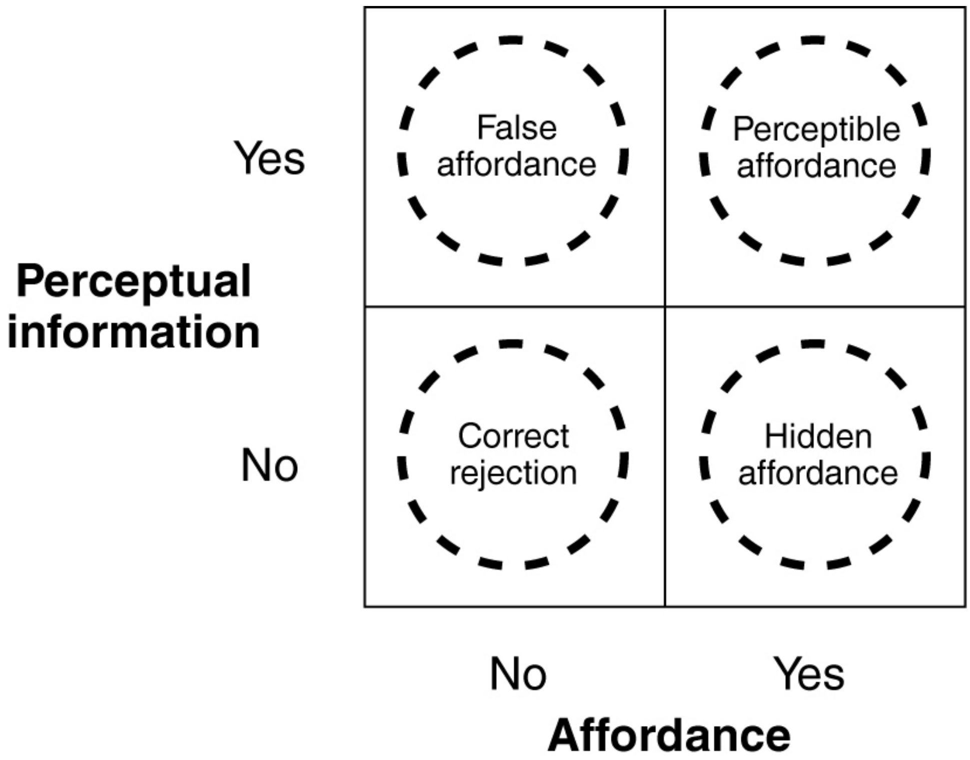

Figure 1: Matrix separating the existence of affordances from the information available about them, leading to four categories. Based on Gaver (1991)

listed on the chain's menus (Harford, 2006): the ability to buy a short cappuccino is a hidden affordance, while the abilities to buy the sizes actually on the menu are correctly perceived affordances (assuming the customer has the financial capability to do so: Gibson (1979, p.127) makes it clear that an affordance must "be measured relative to the animal").

2.1.3 Taking the easiest choice

Where making things easier or harder 'works' to influence behaviour, it may often be because people take the 'easiest' choice in situations, particularly where they don't have time or the skills or even sufficient interest to consider the options available in more detail. This may be *satisficing* (Simon, 1956; 1969), and exploiting an awareness of this in a design sense is not necessarily about treating users as lazy, but recognising that people are busy, time-constrained, and trying to solve problems in their immediate environment (Krug, 2006).

As a special case of affordances and constraints, default settings can be important here, because many people never change them. The case of organ donation defaults is quite well-known—countries where by default everyone is a potential donor, and ones needs to opt out of the system rather than opting in to it, typically have massively higher rates of donation. If products and services can be deliberately designed so the easiest choice, or the default, is the 'best' one (the safest, the healthiest, the most sustainable, the most socially beneficial), or the 'less desirable' choices are harder (more hassle to achieve, or even impossible), there is significant potential to influence behaviour. This could involve extra technology, or be as simple as a parent putting fruit within a child's reach and sweets out of reach. Defaults will be considered in more

Figure 2: These (pretty shallow) steps in Dawlish, Devon, have been labelled as such—effectively *un-hiding a hidden affordance*—presumably because without this, some visitors wouldn't notice, and would hurt themselves or others. Painting a white line along the edge is a common way of improving visibility of steps, but actual labelling is fairly unusual.

detail in a future working paper.

2.2 Relating affordances to other concepts in choice & decision-making

What is missing from the simple division into different kinds of affordances is a *weighting* of some kind for alternative choices, which would determine which of the whole set of correctly perceived affordances are actually acted upon by the user. The processes by which these weightings are assessed by the user and acted upon—and the extent to which the 'cognition' and 'context' blades in Simon's scissors (Simon, 1990) act—are, of course, what much decision research is about. As Gigerenzer and Fiedler (2004) put it, "it is essential to analyse the adaptive match between cognitive and ecological factors."

Choice architecture approached from the designer's domain will probably emphasise the contextual aspects, while approaching it from a cognitive psychology angle will favour the cognitive blade.

2.2.1 Simon's behavioural model

Simon's (1955) categorisation of elements required for a model of rational behaviour is pertinent here. His "set of behaviour alternatives", assuming they are all possible for a user, corresponds to the set of affordances present. The "subset of behaviour alternatives that the organism 'considers' or 'perceives"' corresponds to Gaver's perceptible affordances.

Simon's other elements—"the possible future states of affairs, or outcomes of choice," "a 'pay-off' function, representing the 'value' or 'utility' placed by the organism upon each of the possible outcomes of choice", "information as to which outcomes will actually occur if a particular alternative... is chosen" and "information as to the probability that a particular outcome will ensue if a particular behaviour alternative is chosen" are all elements making up the weighting of the choices.

In most system design situations, for either usability or safety reasons, designers probably want users to have a high degree of certainty about the outcome and payoff of each choice, so the weighting reduces somewhat in complexity. A product (other than a game) where the user had to work out the probabilities of certain outcomes occurring in response to particular interactions would be difficult and probably unpleasant to use, at least until the user had learned patterns and satisficing heuristics to achieve what was desired (although Csikszentmihalyi's concept of *flow* (1991), where a user's skills keep pace with the challenge, may lie behind the enjoyment some users derive from manipulating complex and arcane interfaces).

Yet in many cases, users do not have full information or understanding of what the outcomes or implications of their actions will be beyond the immediate or surface functionality—and this is a major contributor to resource wastage worldwide. For example, one report by a document management company cited by Condon (2006) estimated that FTSE 100 companies typically waste £400 million per year on unwanted printing. That waste has an origin, and it is in millions of individual decision-making errors as users do not fully understand the outcomes of the actions they are taking. The true weighting of the choices users make is either hidden, ignored or poorly understood.

Table 2: Choice architecture subsets and related concepts

<table>
<tr><th>Thaler and Sunstein (2008)</th><th>Gibson (1979)</th><th>Gaver (1991)</th><th colspan="3">Simon (1955)</th><th>Djajadiningrat et al (2002)</th></tr>
<tr><td rowspan="4">Choice architecture</td><td rowspan="2">Affordances</td><td>Perceptible affordances</td><td rowspan="2">Set of behaviour alternatives</td><td>Behaviour alternatives perceived</td><td>Possible outcomes of choices, with pay-off functions and probabilities for each</td><td>Feedforward and feedback</td></tr>
<tr><td>Hidden affordances</td><td>Behaviour alternatives not perceived</td><td></td><td></td></tr>
<tr><td rowspan="2"></td><td>False affordances</td><td rowspan="2"></td><td colspan="2" rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Correct rejections</td></tr>
</table>

2.2.2 Feedforward

The concept of *feedforward*, in an interface design context (Djajadiningrat, Overbeeke, & Wensveen, 2002) helps clarify this linkage from the user's point of view, and make it more prominent: much like the 'tooltip' that invites a user to "Right-click to display spelling suggestions" when hovering the cursor over a potentially misspelt word, feedforward effectively presents the user with a simulation, preview or at least a suggestion of what the outcomes of an action could be, to help support decision-making.

When combined with feedback on the impacts of what the user has already done (see section 3.6), users should be able to help build up their own weightings for the choices in front of them.

2.2.3 Putting this together

Table 2 shows how some of the concepts that have been discussed here fit together. They can be considered subsets of choice architecture which allow a deeper understanding of what the term might mean for designers. It is easy to imagine design 'interventions' occurring in each column, with the level of detail at which this can be done increasing towards the right: while full feedforward and feedback (on the right-hand side) might be the 'best' form of choice architecture for educating the user how to make intelligent decisions about product use, the bluntest form of 'choice architecture' would simply be to remove the affordances (or choices) the designer doesn't want the user to have. It is this reduction in choice which a number of critics of the choice architecture concept fear (e.g. Perks, 2008; Rizzo & Whitman, 2008): using choice architecture purely to constrain users' behaviour rather than enable or motivate.

2.2.4 Implications for designers

- Affordances are a fundamental concept in thinking about how behaviour is influenced by design
- Manipulating perceptions of what actions are possible, or not possible, can be a large component of influencing behaviour

- Hiding or revealing affordances, or deliberately creating false affordances, are additional techniques available to designers
- The term *choice architecture* as used in behavioural economics has some overlap with the concept of affordances: choice architecture is about deciding which choices to make available (or not) to the user, and this process is something designers are necessarily engaged in
- Choice architecture approached from the designer's domain will probably emphasise the contextual aspects, although the dominant cognitive psychology perspective (unsurprisingly) favours investigating cognitive processes
- The concept of *feedforward*, combined with feedback on the impacts of what the user has already done (see section 3.6), users should be able to help build up their own weightings for the choices in front of them.

2.3 Poka-yoke, forcing functions and constraints

> "Then, being much troubled in mind, I said to my men, 'My friends, it is not right that one or two of us alone should know the prophecies that Circe has made me, I will therefore tell you about them, so that whether we live or die we may do so with our eyes open. First she said we were to keep clear of the Sirens, who sit and sing most beautifully in a field of flowers; but she said I might hear them myself so long as no one else did.
>
> Therefore, take me and bind me to the crosspiece half way up the mast; bind me as I stand upright, with a bond so fast that I cannot possibly break away, and lash the rope's ends to the mast itself. If I beg and pray you to set me free, then bind me more tightly still.'"
>
> Homer, *The Odyssey*, c.800 BC, book XII

As is apparent from discussion of physical architecture and behaviour (Lockton, 2011), many situations where design has been used to influence behaviour involve the layout, positioning and fixing (in one way or another) of objects in space. *Barriers* are a major subset of this—Hollnagel (2004, p.69) uses the term to mean "something that stops the passage of something or someone, usually in a physical sense". Hollnagel frames the use of barriers in the context of accident prevention (barriers which aim to prevent an accident taking place in the first place) and barriers for protection, lessening the consequences of the accident (perhaps reducing its impact to a small area or fewer people), and outlines a range of ways of categorising barriers according to various characteristics, moving gradually into metaphorical applications of the 'barrier' concept.

2.3.1 Poka-yoke

A key point about the 'barrier' perspective is that it effectively treats accidents as 'unwanted behaviour' which can be affected beforehand (reduced or eliminated) through design. A similar view is seen (with errors rather than accidents) in the concept of *poka-yoke* (Japanese: 'mistake-proofing'[2]), in manufacturing engineering—defensive design techniques originally developed by Shigeo Shingo in the context of the Toyota Production System, intended to ensure 'zero defects' in assembly processes (Shingo, 1986). What perhaps sounds like a harsh zero-tolerance approach to worker error is nothing of the sort: the poka-yoke approach aims to design out possible errors by making it easier for the 'right' behaviour to occur, and more difficult or impossible for the 'wrong' behaviour: "Too often, we blame people for making mistakes. Especially in the workplace, this attitude not only discourages workers and lowers morale, but it does not solve the problem. Poka-yoke is a technique for avoiding simple human error at work." (Nikkan Kogyo Shimbun, Ltd. & Factory Magazine, 1989).

Shingo's original 1961 example involved a factory manufacturing a device with two switches, each of which needed a spring inserted underneath it, under contract to the parent company. Workers picked the springs from an open box of hundreds of springs, and often forgot to insert one of them—causing ill-feeling and extra inspection expenses between the companies, and within the factory as workers were admonished for their forgetfulness. Shingo's observation was that it would be possible to create a physical analogue of a checklist—by simply introducing a small dish, into which the worker would first place two springs, before inserting them into the switch: "If any spring remained on the dish after assembly, the worker realized that the spring had been left out, and the assembly was then corrected" (Shingo, 1986, p. 43). Grout (2007) sees this sort of poka-yoke as 'putting knowledge in the world' rather than requiring the number of springs to be 'knowledge in the head', using Norman's terminology (Norman, 1988/2002).

This low-cost, simple change eliminated the problem of missing springs, and over the next decades Shingo and others inspired by his ideas developed a large range of interventions, some using technology such as limit switches and sensors to ensure that operations took place in the right order, or warn if they were going wrong, others using jigs and templates to ensure correct orientation of parts, and so on. Shingo divided the interventions into 'control' poka-yokes, designed to prevent errors occurring by making it impossible or difficult to proceed until the error is corrected, and 'warning' poka-yokes such as lights, buzzers, information displays and reminders of various kinds, alerting workers to the presence of an error, abnormal condition or extra step which needed to be performed. Warning poka-yokes, in the form of different kinds of feedback, will be discussed further in section 3.6.

Other poka-yoke methods such as the use of 'go/no-go' gauging, templates and jigs (Chase & Stewart, 2007) may fall somewhere between 'warning' and 'control', alerting the worker but not always (depending on context) preventing the operation continuing. While developed in the context of manufacturing, the poka-yoke concept has been applied in other fields, for example

[2]It is useful here to make a distinction between types of error: in human factors terminology, *mistakes* "involve a mismatch between the prior intention and the intended consequences" (Reason, 1990, p.6), while *slips* and *lapses* are errors where the user's intention may be correct but the correct action does not occur (Norman, 1983). As Reason (1990, p.9) puts it, "a series of planned actions may fail to achieve their desired outcome because the actions did not go as planned [e.g. slips or lapses] or because the plan itself was inadequate [e.g. mistakes]." In driving a car, changing up a gear before trying to accelerate would be a slip if done inadvertently (finding the wrong gear) but a mistake if the driver believed this was the correct way to use the gears. In view of these definitions, *poka-yoke* would probably be better translated as 'slip-proofing' (Grout, 2007, p. 3), or certainly 'error-proofing', to include a wider range of errors. Shingo's original term was *baka-yoke* ('foolproofing'), but he recounts that, "around 1963, when Arakawa Auto Body adopted a 'foolproofing' device to prevent seat parts from being spot-welded backwards, one of the company's part-time employees burst into tears…"Have I really been such a fool?" she sobbed… When the department head told me this story, it was clear to me that 'foolproofing' was a poorly chosen term." (Shingo, 1986, p. 45)

Grout (2007) has produced *Mistake-Proofing the Design of Healthcare Processes*, an extensive guide systematically applying principles of poka-yoke (and other methods) to patient safety—a field in which design and human factors have much to offer in terms of influencing behaviour of both staff and patients (Lane et al, 2006). It is not a major leap to consider inefficient or non-optimal operation of a consumer product by a user as an 'error' (whether mistake, slip or even simply laziness), and some poka-yoke-style techniques as an appropriate basis for designing systems to alleviate the 'error'.

2.3.2 Forcing functions

There is a clear parallel here between Shingo's control poka-yokes and what Norman has called *forcing functions*, "something that prevents the behaviour from continuing until the problem has been corrected" (Lewis & Norman, 1986, p.420). Norman (1988/2002) identified three types of forcing function—*interlocks*, *lockins* and *lockouts*—all of which essentially force a user to carry out operations in a certain order.

Interlocks The interlock on a microwave oven door prevents the oven being run with the door open. Interlocks in ATMs return the customer's card (and make sure it is removed from the slot) before dispensing cash, making it less likely that the user's card is left behind (this is covered in more detail in Lockton et al 2010a).

Norman discusses (1988/2002, p.134) one of the most famous examples, the seat-belt interlock on car ignitions, which forced a driver to fasten his or her seat-belt before the car's ignition would work. Championed by Lee Iacocca, president of Ford in the early 1970's, 'Interlock' was briefly made mandatory on new cars in the United States, but it was deeply unpopular and provoked drivers to defeat it, e.g. "many people kept their seat-belts buckled—but without wearing them" (Iacocca, 1984, p.315). As a result, "[i]n response to public pressure, Congress took about twenty minutes to outlaw Interlock. They replaced it with an eight-second buzzer that would remind passengers to buckle up" (Iacocca, 1984, p.315).[3] Latour (1992, p.225) suggests that such a buzzer, because it is "so high-pitched, so relentless, so repetitive that I cannot stand it", still effectively involves "forcing me... to obey the law".

Interlocks have been proposed for crime control, preventing illegal acts by the user, such as a breathalyser fitted to a car's ignition system so that only when the test is 'passed' can the car be started. These have been fitted by manufacturers such as Volvo as standard, and also mandated for drivers previously banned for drink-driving (Weinrath, 1987). There are also variants of the idea which would also deal with overly tired or drugged drivers, e.g. the 'Simple Simon' memory game using coloured lights, used on the MG/British Leyland SSV1 'safety car' prototype in the 1970s: "Get the (randomly generated) sequence wrong three times in a row, and [the driver] would have to wait an hour before being allowed to try again. While designed primarily as a safety device, this feature also doubled as pretty effective immobiliser" (Berridge, 2004).

Lockins and lockouts Related to interlocks are lockins (in a different sense to the economic usage) and lockouts. A lockin is a forcing function which prevents (or delays) a user from stopping an operation or action which is deemed important. In product terms, an example might involve certain buttons or keys being temporarily disabled, perhaps where accidentally

[3] In Shingo's terminology, this is replacing a control poka-yoke with a warning poka-yoke.

pressing them would be detrimental. Norman (1988/2002) suggested the idea of 'soft' off switches for computers, which permit files and settings to be saved before allowing the power to be cut, and indeed such soft power switches are now the norm.

Lockins with strategic intentions include 'nag' screens on software which require the user to wait a certain amount of time before clicking 'OK' (i.e. exiting the current 'operation') in the hope that a promotional message will be read (or that the irritation will become sufficient that the user registers, or pays for, the product (Fogg, 2003, p.106). In some cases, this type of lockin is used to increase (marginally) the likelihood that an end-user licence agreement will be read, by requiring that the user at least scroll to the bottom before proceeding. Lockouts are perhaps closest in concept to Hollnagel's barriers: an example given by Norman is a gate on a staircase to prevent people, in a panic (e.g. in the event of a fire), accidentally running downstairs past the ground floor and into a basement (Norman, 1988/2002).

2.3.3 Constraints

Norman considers forcing functions within a wider field of behaviour-shaping constraints, considered alongside affordances (see section 2.1). Sometimes this is about "deliberately making [certain] things difficult" (Norman, 1988/2002, p. 203) in order to constrain users' behaviour to what is desired; Krippendorff (2006, p.108) notes that this is simply because "[t]he range of possible uses of artefacts is usually far larger than anticipated by its designers".

In an environmental sense, rationing of electricity, water, printer paper and so on might be considered as a constraint, even if not 'true' rationing but simply establishing a resource as 'finite' from the user's point of view, within a limited context, by using the system to set limits or targets which can be exceeded, but only with extra work, costs, or commitment by the user. Coin-operated electricity meters fall into this category, but do not afford users the granular level of control over switching off individual devices that would be possible with a modern energy monitoring system. As Darby (2006) puts it, the fact that "approximately 85% of electricity consumers and 90% of gas consumers in Great Britain pay for their energy in arrears... is not conducive to conservation, or to control of costs." In Northern Ireland pre-pay keypad meters offer a 2% discount on electricity—the reverse of the situation in much of the UK—and as such, around 25% of households use them, using around 3% less electricity than households paying in arrears (Owen & Ward 2006).

Lilley (2005) notes that Unilever's introduction of detergent tablets was in part a strategic tactic to attempt to ensure that users do not use more (or less) than the optimum amount of powder for each wash: pseudo-rationing in the form of portion control. Alternatively, resource sharing, as simulated by the 'Watt Watchers' system (Fischer et al, n.d.), places a constraint on the total amount of power (or other resource) being drawn at any moment in a system, causing users to co-operate with each other to moderate their consumption. In terms of simple physical constraints, smaller sinks (or sinks which noticeably expand when they are filled beyond the "inscribed" capacity—such as the Cranfield University/Electrolux Smart Sink (Sherwin et al 1998)) set an upper limit on the amount of water that can be used. Smaller rubbish bins (e.g. in a kitchen) make users more aware of the amount of waste they are generating, since the rubbish will have to be 'taken out' more often, and hence may encourage sorting of waste for recycling and better compaction of waste in the home.

Applying some of these affordance- and constraint-based techniques to the interaction between user and system, in the context of influencing more sustainable behaviour, suggests a variety of specific implementations, some of which already exist, and some of which are purely speculative. It should be noted that a number of these implementations may, depending on how they are presented to users, become seen as excessive constraints on user behaviour. For example, light fittings can be designed so that only approved low-energy components will fit, as is the case with the Eaton MEM BC3 range of lightbulbs and lamp-holders (Eaton Corp. 2003; Lockton 2007), created to meet UK Building Regulations requirements for lighting points in new homes which will only accept low energy lamps (Office of the Deputy Prime Minister, 2002, p. 17) by compelling users to buy special 3-pin bayonet compact fluorescent bulbs (functionally identical to standard CFLs) and preventing the fitting of 2-pin bayonet bulbs entirely (whether incandescent filament or CFL). This creates an economic lock-in, not generally in the consumer's interest, and likely to provoke adverse reaction, as the readers' comments appended to a blog post on the subject, Lockton (2007), demonstrate.

Self-control and choice editing There is also the possibility of deliberately introducing constraints into the environment to shape one's own behaviour—perhaps 'enforcing' self-control—using what Ainslie (1982) has called *extrapsychic devices*, such as Odysseus's asking to be bound to the mast in the extract opening this section; Baron (1994, p.521) suggests that "[w]e can throw away the bottle of scotch, or throw away the ice cream we are trying to avoid (so that when we want it late at night, it will not be there, and it will be too late to buy any)."

There are parallels with the idea of *commitment devices*, arrangements which people make in order to make it more likely they will stick to a goal—for example, promises to other people, or even financial 'commitment contracts' as used by StickK.com (Ayres, 2010). While they are usually discussed in a behavioural economics context, commitment devices can be physical constraints, deliberately self-imposed—Bryan et al (2010) mention ideas such as cutting up credit cards, taking a fixed amount of cash out to a party, and leaving paperwork at the office rather than bringing it home, while Ariely (2008, p.122) mentions the 'ice-glass' method for reducing impulsive spending: "You put your credit card into a glass of water and put the glass in the freezer. Then, when you impulsively decide to make a purchase, you must first wait for the ice to thaw before extracting the card. By then, of course, your compulsion to purchase has subsided."

The ultimate behaviour-shaping constraint may simply be removing a function entirely—what might be termed feature deletion, or in policy terms, *choice editing* (e.g. Sustainable Consumption Roundtable, 2006). The intervention by Dr John Snow, who "took the handle off the Broad Street pump in 1854, terminating that pocket of the Soho cholera epidemic by cutting off the supply of contaminated water" (Goldacre, 2008, p.105) is one of the most famous examples here. In Ian Fleming's *Dr No* (1958), a luxurious hotel-type room in which Bond finds himself only signals that it is a prison by the absence of door handles. Various politicians have also proposed removing standby buttons from consumer electronic products (Sunday Times, 2006), with the aim of reducing energy use. A legend often cited in discussions of game theory (e.g. Slee, 2006) states that William the Conqueror burned the boats that brought him to England to demonstrate his commitment and prevent his men fleeing, although as Kay (2005) finds, along with a similar story about Hernán Cortés, historical evidence does not support this.

2.3.4 Implications for designers

- The *poka-yoke*, forcing function and barrier perspectives effectively treat errors and accidents as 'unwanted behaviour' which can be reduced or eliminated through design; it is not a major leap to consider inefficient or non-optimal user behaviour as an 'error' and design accordingly.
- Design can make it easier for the 'right' behaviour to occur, and more difficult or impossible for the 'wrong' behaviour.
- Real, simulated, perceived or self-applied constraints can be seen alongside affordances as important components of design to influence behaviour.

3 Information flows as a leverage point

In section 1, Meadows' (1999) classification of leverage points was introduced, and the idea of working with *information flows* was extracted as a potentially relevant approach for designers seeking to influence behaviour. These interventions involve changing what information about a system is available, and to whom, at different times. One of the examples Meadows (1999) gives in her original treatment of 'the structure of information flows' directly relates to building energy use:

> "There was this subdivision of identical houses, the story goes, except that for some reason the electric meter in some of the houses was installed in the basement and in others it was installed in the front hall, where the residents could see it constantly, going round faster or slower as they used more or less electricity. With no other change, with identical prices, electricity consumption was 30 percent lower in the houses where the meter was in the front hall.
>
> We systems-heads love that story because it's an example of a high leverage point in the information structure of the system... It's a new loop, delivering information to a place where it wasn't going before and therefore causing people to behave differently."

Most of the review here concentrates on the literature on information flows and energy use, but many of the same principles can be seen in information-based interventions for other social benefit behaviour changes, such as encouraging exercise or healthier eating.

3.1 Antecedent and consequence information

It is the principle of "delivering information to a place it wasn't going before" which is central to many designed interventions, but there is a further useful distinction here: *antecedent* information, which is delivered before any action has taken place, and *consequence* information, which is delivered afterwards (Tuso & Geller, 1976).

Educational information campaigns are examples of antecedent information, and assume that members of the public will change their attitudes, and hence their future behaviour, in response to the information, whereas *feedback*, as described in the quote from Meadows, is very much consequence information (though of course it is antecedent to the next time the person uses the device). Reviews (e.g. Geller et al, 1982) have found that antecedent information is overall less effective than consequence information (feedback) at influencing energy conservation behaviour, but there are also antecedent techniques such as *feedforward* (see section 2.2.2) which do not seem to have been investigated in as much detail.

3.1.1 Simple prompts

In some situations, very simple in-context antecedent prompts for particular appliances have been tested, most notably with lighting: usually labels or signs placed above light switches in communal areas in workplaces—often in classrooms or shared office areas. Winett (1977) found that signs asking students (or staff) to turn lights off after 5 pm led to lights only being on 40% of the time in rooms where they had previously been on 95% of the time, while signs merely asking for lights to be switched off to save energy had almost no effect. The John Lewis Partnership reportedly uses labels saying 'Switch off, you're burning my bonus' adjacent to light switches behind the scenes in its stores and offices (Independent, 1998) and a number of organisations which aren't able to offer bonuses in this way have taken to emphasising switching off lights as an opportunity to reduce carbon footprint.

3.1.2 Modelling

Modelling is a form of very specific antecedent information where users are shown a 'model' of how they could behave, with the necessary steps explained in a way which gives people the confidence to apply them—usually in the form of a video or TV programme which portrays a typical group such as a family making changes to their lifestyle and seeing the resultant benefits. As Geller et al (1982) put it, "this does not mean just telling consumers, 'Insulate your home', but actually showing them all the processes involved in accomplishing a particular conservation strategy." The main facilitator of this sort of approach from the 1980s onwards in the US was the accessibility of cable TV and latterly VCRs, for the first time enabling programmes to be distributed to users and their effects measured; Winett et al (1985) found that "after one programme exposure (about 20 minutes), viewers adopted simple strategies modelled in the programmes which led to savings of approximately 10% on their home energy use for a substantial part of the cooling and heating season."

Elements of the modelling approach are apparent in some current initiatives such as the UK Government's Act on CO_2 calculator, which offers (after an extensive series of questions) a tailored plan for householders to cut their carbon footprint and (potentially) to save money.

3.2 Context-based approaches

Combining affordance- and constraint-based approaches with changes to information flows leads to context-based approaches to influencing sustainable behaviour, where affordances, constraints or persuasive elements are selectively enabled or displayed depending on users' behaviour at the time. This is a subset of the field of intelligent machines, pervasive computing, smart objects, ambient informatics and so on: systems which automatically adapt their behaviour to information and circumstances in their environment, with artificial intelligence at the peak of the field.

From the sustainable behaviour point of view, 'closed-loop feedback' systems which automatically correct user 'errors', where inefficient behaviour is defined as an error, are a step up from simple 'open-loop' feedback. This approach could involve continuous active monitoring of user behaviour, with 'correction' where necessary (analogous to electronic traction or stability control for cars), or systems which merely compensate for resource-intensive errors directly (e.g. a sink where the tap is switched off when the water reaches a certain level, rather than being allowed to run down the overflow).

If the error correction is sufficiently reliable, users may no longer need to perform certain interactions at all—a washing machine which switches to half-load settings automatically by weighing the load perhaps no longer needs a half-/full-load setting on the fascia. If it can read information about the clothes (e.g. from RFID tags) or even detect the amount of soiling, all the settings may be processed automatically, without user interaction.

At the extreme of the context-based approach would be the 'optimum lifetime product', automatically disabling functions at the 'optimum' point in its life-cycle as part of a product lifetime optimisation strategy (Chalkley et al 2001) with a known amount of hours' use, a known amount of wear, and a known amount of energy used. This would ensure that products returned under manufacturers' take-back schemes are in predictable condition and replaced at the most efficient point to do so; this approach may be most appropriate for a product -service system, where the user effectively rents the functions provided rather than owning the appliance outright. Many office photocopiers and printers are currently provided under this kind of arrangement: other appliances might be able to benefit from a similar scheme.

3.3 Differences between information use in different contexts

One of the main differences between interventions to influence energy use in particular contexts, e.g. when comparing residential and workplace contexts, is that where individuals are no longer paying for energy themselves, some of the price-based techniques may not be effective. The effect is also apparent (and more directly comparable) in so-called master-metered residential developments (where utility bills are included in the rent). Lutzenhiser (1993) quotes Stern et al (1986) who claim that in the US, master-metered apartment complexes use on average fully 35% more energy than individually metered sites. It is not known if this level of difference still holds in the US (or indeed in the UK).

Hackett & Lutzenhiser (1986) found that within master-metered complexes, there is significant variation in behaviour: "differences as large as 300% between nearly identical households" which suggests that it is not universally true that people will waste energy if they don't have to pay for it. This may hold up empirically for workplaces too: someone in the office may be fastidious about turning off the lights, while someone else doesn't bother. The interaction between many different groups—building owners, the companies renting a buildings, facilities managers, individual staff, architects (at design time)–results in the energy use for a workplace, but more research is clearly needed to understand these interactions, how they contribute to wasting energy, and how to influence behaviours.

Walker (1979) put together a programme in which apartments in a master-metered complex were randomly checked, and if residents were behaving in an energy-efficient manner (windows closed if the heating or air conditioning were on, reasonable settings for thermostats), the residents received \$5 payment. These incentives cost the apartment managers \$200 per month in payments, but saved \$320 in electricity—reductions in electricity use of 2.2% in the heating season and 8.6% in the cooling season were obtained. It is not unthinkable that a similar scheme could be run in other contexts such as workplaces, or indeed a scheme where offices compete with each other to reduce their energy use, with the winners receiving some kind of bonus. Chandler et al (1978; cited in Cone & Hayes 1984) ran this sort of competition between college dormitories (who already had a degree of rivalry) and managed to obtain a 10% reduction in energy use. Longer-term effects may not be maintained, though, once the competition is over, which suggests the establishment of an ongoing league or weekly / monthly award.

Cone & Hayes (1984) relate a relevant anecdote here, which touches on both energy literacy and profligacy:

> "In one of our studies on energy conservation... we attempted to reduce electricity consumption in a married-student housing complex. These apartments were rented,

> very cheaply, and utility costs were included in the rent... It was cold outside that day. All of the heaters in the apartments were undoubtedly going full blast. Strangely, however, the sound of an air conditioner came from one of the apartments in the complex. Upon further investigation, the reason became clear. One of the residents apparently did not like how warm his living room got from the stationary gas heater. Rather than turning down the heater, he had adjusted the temperature by simultaneously running the air conditioner!"

As mentioned in section 3.1, the assumption that education and information lead to attitude changes (antecedent strategies), which then lead to behaviour change, is widely regarded as too simplistic to be true in all cases: e.g. Lutzenhiser (1993) argues that "rather than conservation attitudes necessarily preceding behaviour, behavioural changes can also result in new energy attitudes—attitudes, action, and rates all being elements of institutionalized energy use arrangements."

In a simple example, someone who has lived in a rented property with a prepayment coin- or keymeter and has effectively been forced to behave carefully with electricity use, may develop a pro-conservation attitude and habits which are retained later in life and in other areas such as the workplace—the behaviour preceded the attitude. In more complex examples, the phenomenon of *cognitive dissonance* may come into play, when people adjust their attitudes to be consistent with their behaviour (or the other way round). This seems a particularly pertinent consideration for situations where people's behaviour may be different in different contexts, perhaps due to social effects.

3.4 Information campaigns

Information campaigns—social marketing—are a major component of government strategy on environmental behaviour change, but as Darby (2006) notes, "information on its own has a poor track record in achieving energy conservation. While people may appreciate the message, few are likely to be spurred into action." Staats et al (1996) evaluated a 2-month public information campaign in the Netherlands intended to raise public understanding of the greenhouse effect and ways of changing behaviour to address the problem, and found that while there was some increase in knowledge, the effect on (self-reported) behaviour was very slight, and mainly "limited to a group that already showed more environmentally favourable behaviour before the campaign started."

Heberlein (1975) carried out a 'secret' study of how information campaign affected domestic electricity consumption: he sent particular households informational pamphlets, some encouraging conservation, some encouraging consumption, and read their external meters himself for 12 days before and after receiving the pamphlets, without telling any of the householders they were part of a trial. None of the households changed their electricity usage one way or the other. Heberlein returned a year later, after the massive US government pro-conservation campaigns arising from the 1973-4 oil crisis, and again secretly read the meters. Again, he found no difference in consumption from the original levels read the previous year.

However, in some cases, the effects of campaigns have outperformed feedback and other measures after studies have ended: once the displays or feedback devices are removed, those building users may revert to previous levels of energy use (Hayes & Cone 1977) while people who have received information on energy saving and started to conserve energy during the study, without having any feedback devices, may continue with their beneficial behaviour afterwards (Ester, 1985, cited in Lutzenhiser, 1993). In this sense, then, it seems as though information campaigns may be best suited as longer-term interventions, aiming to increase users' understanding of, and interest in, environmentally or socially beneficial behaviour so that they care about it and are more likely to respond favourably to feedback or other shorter-term interventions.

Wilson & Dowlatabadi (2003), reviewing work in this area applying social psychology and behavioural economics approaches, concluded that "the most effective information in promoting residential energy efficiency" is "simple, salient or vividly presented, personally relevant and easily comparable", rather than "technical, detailed, factual, and comprehensive" (Yates & Aronson, 1983); Abrahamse et al (2005) add that such information must also be specific (i.e. presented in a way which makes it applicable to specific situations). It is also important (Farhar & Buhrmann, 1998) that the information provider—which may be a government agency, local authority or a service provider such as the electricity company—is perceived to be trustworthy and credible in terms of relevant expertise.

3.5 Source credibility

This combination of trustworthiness and expertise is often referred to as *source credibility* (e.g. Fogg and Tseng, 1999), and it would seem apparent that where trust in the organisation doing the 'persuading' (e.g. a utility company) is low, perhaps because of perceived conflict between their profit motive and messages about conservation, messages delivered by other organisations might be perceived as more credible.

Lutzenhiser (1993) cites "one marketing experiment in which solicitations for a programme were made on three different letterheads: the utility company's, a joint utility-county government letterhead, and the county's alone. The latter received a significantly better response" (Miller & Ford, 1985), going on to suggest that "community-based, nonprofit contractors" might be the most credible sources in the context of, for example, weatherproofing advice.

It is easy to imagine that programmes very clearly run by local people in a community (e.g. a series of electricity meter trials carried out in Talybont-on-Usk, Brecknockshire: Kidd & Williams 2008) could have a similar effect, particularly if tailored to individual households rather than presented in a one-size-fits-all mass dissemination style. Geller et al (1982) note that "a common reply... from state DOE [Department of Energy] personnel when asked about residential energy conservation programmes was: 'We have a great programme. We've sent out a million informational brochures.' It is quite clear now that a million brochures sent to consumers does not equal a million kWh saved each day!"

Gates (1976) studied energy utility companies' advertising in the US, which switched from promoting consumption to conservation as a result of the 1973 oil crisis, and found that overall the advertising had little effect one way or the other on electricity sales, with other factors such as appliance stock and weather being far more significant. As Gates put it, "if [energy utility] advertising has been unsuccessful in selling more electricity, is there any hope that it can be successful in selling less electricity?"

3.6 Feedback

Going on to consequence information strategies, *feedback* in many different forms is the core of the majority of information flow interventions. As Wilson & Dowlatabadi (2007) put it, "to conserve energy, home occupants must know how behaviour and energy use interrelate and must be motivated to conserve... information provides the former, incentives provide the latter, but only feedback provides both."

Some researchers distinguish absolutely between *direct* feedback (e.g. a real-time display) and *indirect* feedback (e.g. quarterly reports) as if they are mutually exclusive, but it is clear that in practice these can often be employed in conjunction. It makes sense to think of the 'oftenness' (frequency) and 'completeness' of feedback as being variables, the effects of which can be tested. Fischer (2008) proposes that feedback methods can be assessed according to frequency, duration, content, breakdown, medium of presentation, comparisons, and combination with other instruments and this approach will be roughly followed here.

3.6.1 Frequency & duration

The question with frequency is how often feedback should be given—from quarterly or annual reports or bills right down to instantaneous, continuous real-time monitoring. Abrahamse et al (2005), reviewing 38 studies on interventions to influence household energy use, found that "results... seem to suggest that the more frequent the feedback is given, the more effective it is", but also noted Kantola et al's work in Australia (1984) which showed that a single piece of feedback evoking considerable cognitive dissonance can reduce energy use. In this study, users who were "informed of an inconsistency between their previously measured attitudes toward conservation and actual high consumption of electricity" tended to reduce their electricity consumption, at least in the immediate period after the dissonance was evoked. It is, however, hard to see how this sort of effect could be maintained in the longer term.

It does seem as though frequent, quick or instantaneous feedback is effective (e.g. McCalley & Midden, 2002; Hutton et al, 1986; van Houwelingen & van Raaij, 1989), often in conjunction with some kind of goal, challenge or standard which participants are encouraged to aim for. The standard type of household utility bill arriving every few months (and often estimated) is, as Gaskell et al (1982) put it, "a form of feedback in which the feedback loop is too far removed from the use of inputs to have any information value" (quoted in Darby 2006). Fischer (2008) suggests that "quick feedback would improve the link between action and effect, and therefore, increase consciousness about the action's consequences. Furthermore, persistent effects would be more likely if feedback is given over a longer time, because new habits can form during that time." In her review, she found that trials where the feedback was daily or more frequent (e.g. real-time) all outperformed trials where the feedback came at intervals of a month or more. Traditionally, however, real-time feedback has been expensive and difficult to implement, which has led many researchers to concentrate on summary feedback either daily or weekly. Nevertheless, they have often obtained quite significant results, again, particularly when a goal is set (e.g. Becker, 1978; Winett et al, 1979).

3.6.2 Combining feedback with goal-setting and commitment

A number of successful studies have combined feedback (ideally frequent) with a goal, either set by the experimenters or by participants themselves. Becker's (1978) study suggests that a difficult goal may be more effective than one that is too easy, since it gives householders a challenge which, even if they don't achieve it, is 'asymptotically' within reach to use Pink's (2009) phrasing. Nevertheless, the goal must be realistically achievable: if people believe they have no hope of reaching it, however hard they try, there is little incentive to try. The 'sweet spot' will necessarily differ for different people in different circumstances, though it is unclear how best to assess this.

Commitment and consistency will be discussed in a future paper, in the context of Cialdini's work, but it is worth considering them further here in the context of feedback. To some extent, the experience of committing oneself to a goal (or being seen to do so) may be an important part of achieving the goal in itself. Freedman & Fraser (1966) asked a sample of householders to sign a 'Keep California Beautiful' petition, and then soon afterwards a different experimenter to the one who had asked them about the petition made an (on the face on it) irrelevant request to put up a (quite obtrusive) 'DRIVE CAREFULLY' sign in their front gardens. 47% of these householders agreed, compared with only 20% agreement from a control group who had not been asked about the petition first—suggesting that the commitment to being 'public spirited' in general engendered by signing the petition may have made people feel that they wanted to act consistently with this in other areas of their lives.

Seaver & Patterson (1976) brought a social aspect to the commitment strategy, by sending a decal (sticker) saying 'We are saving oil' to householders whose heating oil consumption was lower than for the same period the previous year, and then monitoring how much those households used after receiving the decal, compared with groups who did not receive it: they found a 10% reduction in oil use. Whether or not householders actually did anything with the decal, it represented some 'commitment', "a social recognition of their efforts to save oil" (even if not intentional). Where householders did put the decal up somewhere visible, perhaps where neighbours could see it, there may be a social commitment effect (see below): neighbours now expect the family to be energy efficient people, even though they have no way of monitoring each other's oil usage. Cone & Hayes (1984) suggest that "the effects might be stronger if the decal was sent to all families regardless of consumption. You can easily imagine that just displaying the decal would lead neighbours and others to ask what the families are doing to save oil. This, in turn, might lead them to attempt to practise what they preach."

3.6.3 Ultra-simple feedback

Feedback need not be complex: one of the earliest intervention studies on energy use, Kohlenberg et al (1976), simply involved a 40W light bulb positioned in householders' kitchens which would illuminate when the household was using high levels of electricity—with the aim of encouraging householders to shift consumption to off-peak periods. This proved effective to some extent, particularly when combined with financial incentives. (It is interesting to note that Kohlenberg et al suggest that "Voltage reductions that would dim the lights, or an easily readable watt-hour meter in the home are two of the many possibilities for providing feedback devices that might influence consumption.")

Another 1970s study, Becker & Seligman (1978) used a simple flashing blue light to signal to building users that the outside air temperature was low enough (68°F) that opening a window would be better then keeping the air conditioner running. Only switching off the air conditioner would extinguish the light. Users with the blue light device used 15.7% less electricity during the trial than those without it. Some modern smart meters and energy monitors incorporate a 'load limit' alarm which sounds when a predetermined level of energy use is reached.

Very simple feedback is also the principle behind the Interactive Institute's Power Aware Cord, an extension lead where the cable is illuminated when power is being drawn, in the process intended to improve energy literacy (Gustafsson & Gyllenswärd, 2005, quote one tester who exclaimed that "I think this is what power cords look like on the inside. You have just made it transparent!")

3.6.4 Types of information / content / units

In the literature relating to feedback on energy use, there is unfortunately no consensus on the units or types of information than feedback should provide to be most effective. Many studies have used both kWh (or equivalent) units and monetary costs. Environmental impact in term of carbon footprint is a relatively new possibility here. Abrahamse et al (2005) note that "It is not clear whether it makes a difference to give feedback in terms of monetary rather than environmental costs, since studies investigating this difference did not find any (e.g. Brandon & Lewis 1999; Bittle et al 1979–1980)." Fischer (2008) suggests "tailoring the kind of information given to the potential motives and norms of the target group," which would accord with a segmentation approach.

Energy literacy comes into play: Kidd & Williams (2008) in trials with the Efergy energy meter found that "most households had no sense of what their current consumption rate might be in numerical (kW) terms because they had never before seen it expressed as a live number. The number initially displayed was fairly meaningless to them until they saw it jump up or down for the first time," while Anderson & White (2009) found a mixture of levels of understanding from their focus groups—a typical example:

> "Nobody understood either Watts or kilowatt-hours. Everyone understood money. After an explanation from the facilitator, two participants said they understood kilowatt-hours for the first time but most remained baffled. Their knowledge of how much power familiar household appliances consumed was poor. For example, they guessed the power consumption of a kettle to be: 60W, 155W, 800W, 1kW (twice) and 60kW."

Some groups suggested £/day or £/hour as their preferred units for use on a feedback display; no-one liked the Wattson's £/year measurement. Anderson & White express an interesting point about units:[4] "It is particularly unfortunate that the unit that expresses a rate, the Watt, sounds like a unit of quantity while the unit of quantity, the kilowatt-hour, sounds like a rate. In the discussion of the power ratings of different appliances several participants asked if we were talking about 'Watts per second' and the kilowatt-hour was as often referred to as 'kilowatts per hour' as it was [otherwise] correctly described."

[4]The author is currently working on a study to investigate this issue further, since it seems crucial yet under-explored in the context of energy display design.

3.7 Disaggregation & feedforward

Costanzo et al (1986) argued that "the impoverished, undifferentiated information communicated by the monthly bill makes accurate understanding of energy use [by building users] unlikely," and the use of feedback disaggregated by appliance would help considerably here. Darby (2006) notes that:

> "An instantaneous, easily accessible display may give the consumer adequate information on different end-uses, by showing the surge in consumption when the kettle is switched on, or the relative significance of a radio, vacuum-cleaner or toaster. Information on how energy use is disaggregated among end-uses in an average home can also be given on the bill, as a general guide. Accurate, frequent billing will give the householder a much better sense of the heating load at different times of year than can be gained from a direct debit statement... [although] there are no data on persistence of effect for this type of feedback. The argument for it rests on the educational effect in raising awareness of the relative demand from different appliances."

It might also be considered that disaggregated device data of the kind made possible by companies such as Sentec and ISE / Navetas—which shows users how much energy is being used by different devices—could act as a significantly improved method of real-time feedback. There is also the possibility that relatively generic data on the costs or energy use of different appliances could be incorporated into a kind of 'energy price label' for appliances—using the principle of *feedforward* (Djajadiningrat et al 2002; see section 2.2.2)—presenting the user with a simulation, preview or suggestion of the outcomes of an action. This would not require actual disaggregation of appliance data, simply that a credible database of product use characteristics be available.

Appropriate feedback could help users to develop more accurate *mental models* of how the engineered systems around them actually work, particularly in energy terms—for example, Sweden's Interactive Institute has done work including a computer game, 'The PowerHouse' which aims to teach teenagers more about energy-using behaviours in the home, and the impacts of using different appliances in different manners, through simulating a household, the appliances, and characters which interact with them (Bång et al 2006). The Institute's Static! Research project also led to a number of other interesting energy-use feedback concepts, including an electric radiator using thirty-five 60W incandescent lightbulbs (to illustrate clearly to users the significant heat by-product of incandescent filament household lighting) (Gyllensward et al 2006), and an 'Erratic Radio' which intentionally receives the 50Hz signals from household electric appliances in the area, and uses these to affect the tuning of conventional radio stations, so that the sound quality deteriorates as more appliances are switched on in the room (Ernevi et al 2005).

The above examples help reveal the physical science behind everyday energy use; it is also appropriate to demonstrate to users the financial costs of their behaviour—how much extra it will cost to switch a device on, how much it is costing per minute, how much it has cost in the past month, and so on—and this is something which the new generation of energy monitors are well-placed to permit. For example, Ambient Devices' wirelessly networked 'Energy Joule' (Ambient Devices, n.d.) aims to persuade users to alter their 'discretionary' electricity use in response to signals about the current electricity cost per unit (e.g. reducing use at times of peak demand on the grid), in the process saving money.

3.8 implications for designers

- Information flows involve changing what information about a system is available, and to whom, at different times. The principle of "delivering information to a place it wasn't going before" (Meadows, 1999) is central to many designed interventions. Antecedent information is delivered before any action has taken place, and consequence information is delivered afterwards. Different design considerations are relevant in each case.
- There are a number of different kinds of feedback which it is possible to design, from the ultra-simple to more complex 'closed-loop' systems which automatically correct 'errors'.
- The most effective information campaigns (for home energy efficiency at least) present the information in simple, vivid and personally relevant ways, with the source being perceived as credible.
- More frequent feedback seems to be more effective at influencing users to save energy, but a single piece of feedback evoking surprise (in turn, cognitive dissonance) can also be effective.
- Systems which either set a goal for users, or allow users to set their own goals, in conjunction with feedback, can be effective, and may involve commitments, social proof and other mechanisms.
- The kinds of units or type of information used in feedback need to match the understanding and literacy that users have in relation to the situation being monitored.
- Designing *feedforward*—presenting the user with a simulation, preview or suggestion of the outcomes of an action—may require more data to be available, but offers a new set of possibilities hitherto underexplored.

4 Discussion

This paper has discussed, briefly, some aspects and implications of the use of affordances (and constraints) and information flows as approaches to influencing more sustainable user behaviour through design, drawing on Donella Meadows' framing of leverage points as the initial classification. As noted in section 1, the 'design for sustainable behaviour' use of these leverage points is often in combination with each other: they are overlapping families of strategies.

Talking at the level of affordances, constraints and information flows is probably not sufficiently 'granular' to capture the nuances of specific design techniques in practice, but can be seen as a possibly useful high-level classification for initial engagement with behaviour. For example, we can ask questions such as:

- Are we trying to make it easier or harder for users to behave in a particular way?
- Can we make the 'right' behaviour the easiest one to do? (or the 'wrong' behaviour the hardest?)
- Is there information which would help users make better decisions beforehand?

- Is there information which we could give users afterwards which would help users make better decisions next time?
- Is there information generated which currently does not go to where it would be useful?

All of these can help explore the problem better; the process of answering them will suggest possible design solutions.

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