Social structures that promote change in a complex world: The complementary roles of strangers and acquaintances in innovation

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Abstract. In this paper we offer insights about the type of societies that are more likely to generate and promote innovation. In particular, we present results from a study of innovation through computational social simulations to focus on a structural aspect of societies: their degree of separation and how this social characteristic may be related to what, how and why new ideas and solutions can replace existing wide-spread practices in a society. We focus on the work of design practitioners and sustainable design as an example to illustrate these insights.

1. Introduction

Because of their role in shaping the future, design practitioners such as architects, product designers and engineers can be regarded as initiators or promoters of change in their societies. These professionals synthesise descriptions of future buildings, objects, tools and practices aiming to address existing and future collective needs and wants. Depending on their ability to foresee problems and the consequences of their proposed solutions, designers often modify the way in which people will satisfy their needs and, in some cases, how people will live in the future. In this sense, innovative designers can determine key aspects of our future world, in particular the physical environment, and the way we will live in it.

To define and design the future is a challenging task. There are a number of recent indicators that show that the world as a viable place to sustain life in the future is less than satisfactory and trends suggest that the impacts of our material commodities will keep increasing in coming years. Designers -as well as other professionals involved in shaping the future- may contribute to modify a range of unsustainable practices and associated habits and beliefs that are difficult to change. Examples of behaviour not able to be maintained or supported in the future include resources depletion, pollution, climate change and social inequalities. Future design solutions, such as buildings where we live and work, and objects and tools that we use everyday -their materials, manufacture, use, and disposal- could conform to more sustainable goals such as cradle-to-cradle, extended product lifecycles, alternative energy consumption, and service-by-product replacement.

Designers formulate problems, find new solutions, and challenge existing dominant ideas and behaviours. A pressing design problem is to figure out how different stakeholders will react to new ideas, and how they may modify the original intentions and assumptions built into products to prevent indirect, unanticipated and undesirable consequences [1]. The German term 'schlimmbesserung' refers to a common issue in design: solutions that generate more and worse problems than those meant to be solved. For instance, hidden costs and unforseen practices have shown that the replacement of plastics by natural materials in some products may end up having negative impacts [2].

New technologies or radical new ideas can be applied in the design of innovative artefacts, transforming the set of possible solutions by adding or replacing variables in the design space [3]. However, early solutions within a new design space tend to meet resistance to change and indeed be problematic partly due to their interaction with previous ideas or technologies or simply because of lack of knowledge and expertise. On the one hand, many design cases have shown that the behaviour and consequences of novel complex systems are often hard to predict at the physical level[4]. On the other hand, practices such as social perception and influence, adoption and adaptation of new design artefacts within a society are largely uncertain. As a result, designers often find themselves proposing new artefacts that will affect in unforeseen ways the technical as well as the social spheres of the future.

2. Change in Complex Systems

Although considerable effort is put into foreseeing the potential consequences of new design ideas, the dual socio-technical nature of the design disciplines makes it very hard to predict how new ideas will fit into future scenarios. Namely, it is difficult to:

- foresee what (and why) new ideas or artefacts will be accepted
- estimate the time span and social scope within which new ideas may impact
- anticipate the indirect and undesirable consequences of new ideas or artefacts
- consider how new ideas or artefacts will interact with existing technologies, practices, and beliefs
- visualise how other people may transform new or recent ideas or artefacts during their implementation and use
- predict how other designers may build on new ideas in the design of subsequent artefacts at least in the near future
- estimate the full impacts of new ideas or artefacts for different stakeholders
- anticipate how future practices and scenarios may evolve by the existence or the lack of new design solutions

These and other related questions regarding new design ideas and artefacts can be addressed by considering design practice within its larger context of a complex socio-technical world. Such types of systems have been identified as having a number of characteristics that include distributed behaviour, lever points, numerous interacting elements, aggregation, emergence, nonlinearity, diversity, anticipation, and bounded or limited rationality [5]. The apparent unpredictable emergence of new ideas and their eventual impact in complex systems such as human societies, are likely to be better understood as we engage in the study of these types of characteristics. The study of system dynamics has been considered by some authors as the most adequate approach to understand sustainable development [6].

Distributed behaviour refers to the observation that new ideas are not generated by --and their impact is not controlled by-- a centralised control within a society. Instead, new ideas and solutions are product of the interaction between numerous building blocks of a social system, i.e. individuals including designers and other stakeholders. Lever points (popularly also known as 'tipping points') indicate that at certain key times, a small change of behaviour from an individual or a minority in a social group may trigger large collective changes. Such lever points can emerge in a complex social world because although individuals may behave independently, their behaviour may accumulate or aggregate over time until they reach a self-sustaining pattern, from market fads to paradigm revolutions. Complex groups such as human societies are sources of diverse beliefs, perceptions and interpretations, which make it very hard to predict the range of possible reactions both to problems and needs as well as to new ideas on how to solve them. Given our limited understanding of the socio-technical world that we inhabit, it has remained practically impossible to predict where the next new idea or design artefact will emerge and how it will be received by our societies and in some cases even how the physical laws will affect them in all situations.

This paper presents an initial study conducted through computational social simulation following two main approaches, cellular automata and multi-agency modelling. It focuses more on the type of results obtained and their likely meaning and relevance to our understanding of design as an instrument of change to shape the future, rather than on the technical description of these systems which can be found elsewhere [7].

3. Computational Social Simulation

Computational social simulation refers to the study of social agency through the design, implementation, and execution of computer models usually built under rather simple assumptions with which the experimenter is able to define a series of hypotheses and formally implement and experiment with them to explore their consequences and veridicality. Early computational social simulations emerged from game theoretical approaches such as the early studies on social segregation [8]. Recently, a variety of modelling types, tools, and frameworks have been developed by a growing research community [9]. Such a simulation toolkit can be used both at the stage of identifying opportunities and formulating problems, as well as to foresee the implementation of new ideas into successful and stable design solutions broadly accepted by a social group.

The type of computational systems that we have built in recent years have centred on the idea of a social group (implemented as multi-agent systems or cellular automata) whose members generate and evaluate a range of ideas and practices (represented by numeric values or geometrical shapes) by executing a set of simple rules (value exchange between agents in an *n*-dimensional landscape). This modelling has been framed within a systems view of creativity and innovation --the Domain-Individual-Field-Interaction or DIFI framework [10, 11]. In this application of the DIFI framework, the domain represents the set of values shared by a field, the field is defined by the aggregate characteristics of the group of agents and their interaction over time, and the individual by the set of behaviour rules for different agent roles. By manipulating independent experimental variables at these three different levels, we are able to explore in our computational models the formation of patterns over simulated time of social influence, diffusion, and emergence of new values.

The role of designers in these systems has been modelled as instances of change agents which work towards providing novel solutions to a set of problems shared by large social groups. Typically, in these social simulations a small subset of the population are designer agents, i.e. they compete over a time period by iteratively interpreting the problem and proposing a solution which is conversely evaluated by the rest of the social group. The designer agents learn from the feedback provided by the social group including their adoption decisions and a measure of satisfaction with their adopted solutions. Designer agents also have a learning mechanism that influences their future behaviour based on the overt actions of their competitors and the social adoption of their solutions. Although the evaluation process carried by adopter agents follows a set of rules that define individual perception and preferences (following a normal distribution), social interaction is included as the potential of adopter agents to influence each other's decisions to adopt or reject solutions generated by the designers.

Figure 1 illustrates the architecture upon which our systems are built including the behaviour rules of individual designers, the layers of interaction in fields or social groups of evaluators, and the resulting domain or set of aggregate solutions. In groups which comprise a few hundred adopters, patterns of interest arise such as the emergence of opinion leaders and cycles of convergent-divergent adoption. During a simulation, the system tracks the behaviour of every agent as well as the global patterns of group behaviour. Despite their apparent simplicity, these models of co-evolution generate non-linear effects that emerge from the interaction of their components over time. In this way, researchers are equipped with *in silico* laboratories where they can 'grow up' different states from a set of initial conditions, gaining insights into the role of designers as change agents of complex systems.

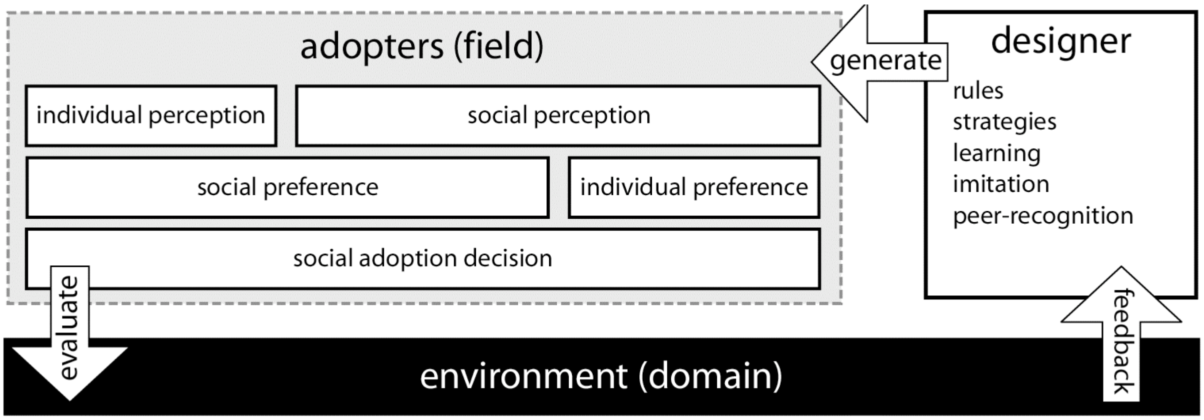


Figure 1 System architecture based on Domain-Individual-Field Interaction [10].

A range of computational social simulations have been built in the last decades in order to understand the exchange of values in groups of agents. Typically, these models have focused on the aggregate effects of individual behaviour interacting in large groups and over large time spans. For instance, the canonical social agent simulation consists of a population of agents represented by cells in a two-dimensional grid which are individually assigned initial numeric values at random and the simulation run shows how a simple instruction to exchange values between adjacent individuals, tends towards group convergence in one dominant value or a group state of lock-in where regions of incompatible values emerge [12]. These systems have been extensively replicated showing that the final outcome (group convergence) is unavoidable although variations do occur depending on variables such as the range of values assigned and the rules of interaction between neighbours or adjacent cells. When group characteristics are studied in this type of models, the main focus has been on the manipulation of group size showing that the size of a society may only determine the time length to group convergence but not the final result.

A converged society represents one in which a dominant value is shared by all or a majority of individuals. This could represent a generalised practice or belief throughout that society such as those considered unsustainable at present. In order to change a dominant practice or value, single agents or minorities may intervene by generating alternative values and presenting them to their social group for evaluation. Previous models had shown that this phenomenon of triggering a social change by a minority in these systems is unlikely to succeed under most circumstances due to the high probability of the new value to be 'eaten' by the continuous exchange of the dominant or wide-spread value amongst most neighbours [12]. However, we implemented a type of systems where we can track the diffusion or spread of new alternative values and found a number of variables that had a direct influence on how difficult it is for a minority to diffuse a new value in their society replacing dominant values [7]. A macro or group-level variable of interest that we present in this paper has to do with how a society may be integrated by more acquaintances or more strangers, i.e. a structural feature of a group.

4. Social Structure: Degree of Separation

Conventional modelling practices in the study of agent societies are limited in that they tend to represent agent societies by an arbitrary two-dimensional grid or lattice of equal width and height (X and Y axis). Agents are represented by cells in this grid, which is usually connected at the ends, i.e. cells located on the left margin of the grid interact with the matching cells that would be adjacent in the right margin of the grid , making it a ring torus as shown in Figure 2. Similarly, cells located on the top margin interact with cells on the bottom part of the grid effectively forming a continuous lattice where all agents interact with the same number of adjacent cells. Existing programming frameworks for social simulation in fact provide this equilateral structure as a default modelling assumption.

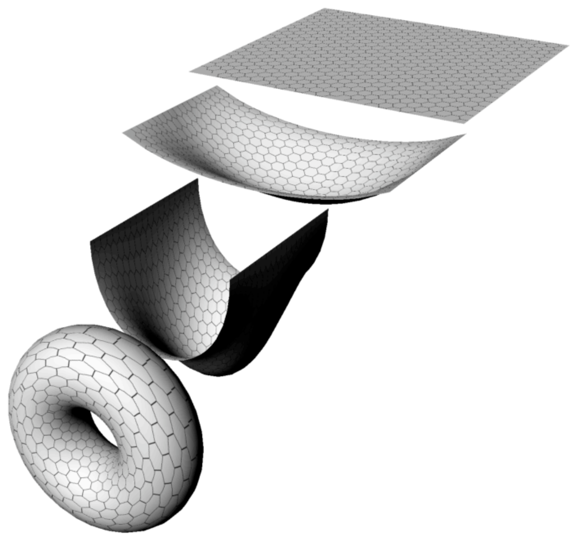
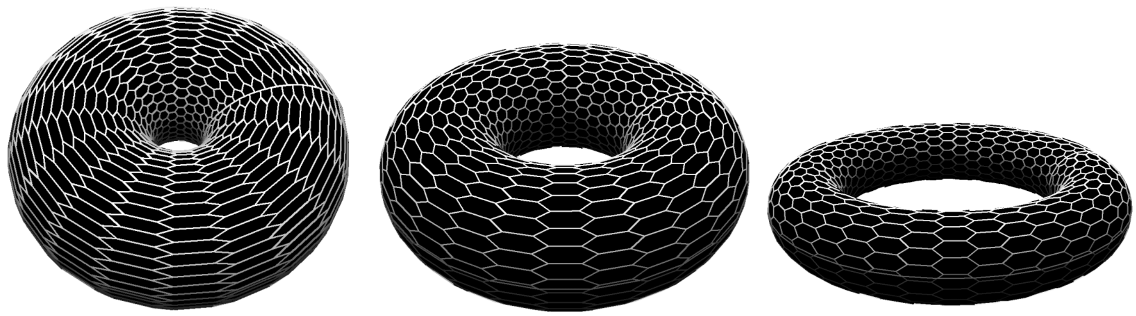


Figure 2 Computational social simulations usually represent social agents as grid cells in two dimensional lattices that form a ring torus shape with same-size axes.

We initially adopted this standard grid modelling practice to replicate some of the key results published in the literature [13]. Subsequently, we devised new experiments and developed new computational modelling tools to facilitate the study of the structure rather than the size of an agent society. Namely, if the size of a group was kept unchanged but its degree of separation was changed, we realised that the diffusion of new values would vary consistently and significantly.

Separation here refers to the social distance between members of a group. The measuring unit is a degree of separation (S_D), which represents a step between a pair of individuals who have contact or know each other. For instance, if individual *A* knows or has contact with *B*, *C* knows *B*, and *A* and *C* do not know or have contact with each other, then the pair *A*-*C* is said to have two degrees of separation. The degree of separation of a social group can be consequently defined as the average number of steps between any random pair of its members. This measure of social 'connectedness' has been illustrated by a popular sociological experiment where people use their personal contacts, such as their close friends, to transmit a message in order to estimate how many friends-of-friends (or degrees) it takes to reach the final destination, i.e., a person seemingly unrelated to the initial sender [14]. Today, numerous websites apply this principle to offer a range of services from friendship and dating to exploring new business opportunities.

Social groups with a low S_D are characterised by agents that share a large number of common neighbours or have contact with a set of neighbouring agents that in turn have contact amongst each other. In this type of societies it is relatively easy for an agent to be in close proximity with any other randomly chosen agent in the group. In contrast, societies with a high S_D are defined as those in which agents have contact with neighbouring agents that are not common to other agents in the group. In these societies, it is less likely that an agent will be in contact or in close proximity with a randomly chosen agent in the group. To understand the results presented in this paper, it is important to notice that the degree of separation of a society can vary even if the group size is kept unchanged. One way to implement this is to arrange same-size groups in different lattices shapes such as varying the radius of the revolving tube of a ring torus grid as shown in Figure 3 [7].



(a) Low S_D (b) Mid S_D (c) High S_D

Figures 3 Ring tori with decreasing tube radii yielding an increasing degree of separation, yet with a constant number of agents (900 hexagonal grid cells here); (a) low S_D; (b) mid S_D and (c) high S_D. Agents in Figure 3(a) can reach any other agent through a small number of neighbours, whilst those in Figure 3(c) require a long chain of neighbours to reach other agents that are further apart.

The main resulting pattern in an agent society where a structural feature such as degree of separation is changed, is that group changes are less likely to take place in societies with a low degree of separation S_D, such as Figure 3(a), than in societies with a high degree of separation S_D, such as Figure 3(c). In societies with high S_D, where agents form more isolated neighbourhoods, the diffusion of new values introduced by agents (i.e., alternatives to dominant or wide-spread values) is more likely to succeed than in same-size societies of equivalent agents where degree of separation is lower or neighbours share more common contacts amongst each other.

This could seem counter-intuitive at first if one assumes that the high level of connectedness in a society of low S_D should facilitate the replacement of dominant values or ideas. As agents talk more often to closer groups of contacts, one could assume that close-knit groups would transfer their values more easily and rapidly. A highly interconnected society effectively promotes a 'flat' landscape where agents do interact more easily, but this has an interesting effect: new alternative values are effectively neutralised by the frequent exchange of the dominant value that flows rapidly across the social group. In contrast, a lower level of connectedness in a society with high S_D, generates a sub-division of the society into large sets of neighbourhoods, or regions of similar agents that share values. This lower tightness in the society is a fertile ground for new alternative ideas to gain momentum and avoid being swept by dominant values. As a result, societies with high S_D show a type of obstacle formation that causes a 'bumpy' landscape to protect nascent values from the free flow that would otherwise strengthen the diffusion of wide-spread values. In graphical visualisations of this simulation, societies with high S_D appear to create 'waves' of alternative values that move unpredictably across the whole population before becoming dominant, or being subdued by other values. Thus, slowing down the diffusion of ideas in a group seems to promote the emergence and acceptance of novelty.

One way to plot this difference is the conventional sigmoid or S-shape curve of diffusion [1], as shown in Figure 4. Our simulations demonstrate that the growth rate of the diffusion curve varies positively with the degree of separation of the group. That is, in high S_D (dashed thin line) the slope of the S-shape curve appears steeper in comparison with low S_D, (continuous thick line) where the growth rate is lower as shown by a more gradual slope of the diffusion curve. This suggests that the spread of new values in a society is speedier as its S_D increases. However, the scope of diffusion as shown by the height of the sigmoid curve results inversely proportional to degree of separation.

New values may diffuse more slowly, but they are likely to reach a larger population in societies with lower S_D. In sum, societies where agents form groups of neighbours that have contact with each other and with each other's neighbours, are more resilient to accept new alternative values and less likely to support a collective change (but changes may eventually have a larger impact), than same-size societies where agents form groups where each member has contact with other agents with which their neighbours have no direct contact.

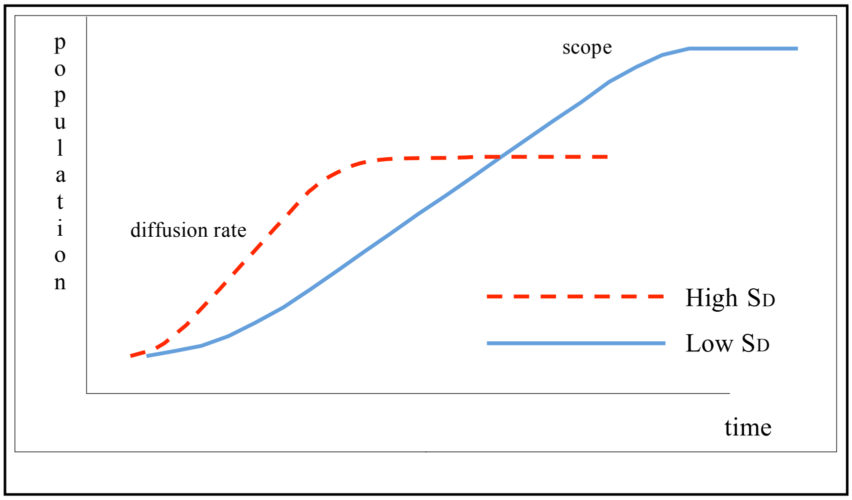


Figure 4 Sigmoid curve of diffusion of innovations. Vertical axis plots the target population, horizontal axis is time. An S-shaped curve shows cumulative adoption of a new idea or practice in a society. This paper demonstrates that diffusion rate and scope are associated to a structural variable, namely degree of separation.

That the degree of separation would present a direct effect on speed and scope of diffusion independently of population size is of significant interest. This association can be explained by the way and frequency in which agents interact with their neighbours. In societies with low degrees of separation, Figure 3(a), agents have contact with a set of surrounding agents that may also be in contact with each other and so new values are repeatedly exchanged across and within adjacent sets of individuals. An agent that passes on a given value in this type of society is more likely to receive the same value from nearby agents, thus promoting resistance to change by decreasing the chances of group adoption of a new value. As the degree of separation increases, Figure 3(c), minority values tend to spread across neighbouring groups more easily due to the increased value variety within sender-receiver pairs. The overall pattern in a society with a high degree of separation is a constant flow of values across sets of neighbouring agents. This indicates that low group densities facilitate social changes whilst group size is not determinant.

In colloquial terms this finding could be phrased as "If the neighbours of my neighbours, or the friends of my friends know each other, then a change of group ideas and beliefs is likely to be more difficult than if my friends and their friends-of-friends do not know each other". That is, our work would suggest that societies where more 'strangers' exist are more open to social changes, whilst societies where more acquaintances or friends exist are likely to reinforce shared ideas and build strong habits and customs, which create resistance to change.

Notice that at the individual level (the cell in the lattice), behaviour rules are kept unchanged and interaction rules within same-size neighbourhoods also remain constant between societies with different degrees of separation. It is at the meso-level interaction between emergent sets of neighbours or 'regions' that very different phenomena takes place. On the one hand, a low degree of separation means that neighbours-of-neighbours tend to repeatedly influence and reinforce each other, making dominant values more resilient. In contrast, a high degree of separation means that a cell's neighbours are not likely to have contact with the same neighbours and thus influence is lower and the group is more receptive to the introduction and diffusion of new values not only within but more importantly, across sets of neighbours or regions.

Different degrees of separation can be said to place social influence at different levels. In societies with a low degree of separation ("where everyone knows everyone else"), influence is at a more general level (i.e., macro-influence), as seen by the emergence of shared values that tend to dominate the whole group. In societies with a high degree of separation ("where it is very hard to know everyone else"), influence is at a more regional level (i.e., meso-influence), as shown by convergence within local groups, coupled with global divergence. This type of result shows that simple computational simulations are sufficient to capture the idea that a social group is more than the sum of its isolated members [9].

In these simulations, all initial conditions and rules of behaviour are kept unchanged except for the variable that defines the degree of separation of these societies. Thus, our results imply that the acceptance or rejection of a new idea can be associated with group characteristics related to global social structure, rather than with any characteristic or behaviour of the individuals involved, or even with any actual feature of the new idea or solution itself. Therefore, to innovate in societies where individuals have contact with common neighbours (low S_D) can be expected to be more difficult than to innovate in societies where they tend to interact with neighbours that, in turn, have contact with other members of different neighbourhoods (high S_D). Our simulations also suggest that diffusion of innovations may reach a larger population (i.e., market segment) and form a *status quo* over longer time periods in societies where individuals have contact with common neighbours (low S_D) than in those with different neighbours-of-neighbours (high S_D).

If high degrees of separation (S_D) can be said to promote variety of ideas, then low degrees would tend to promote resilience and habit-making. New and alternative ideas are therefore more likely to emerge in high degrees of separation, whilst strong beliefs may result in low S_D groups. This suggests that new sustainable practices in design are more likely to emerge in societies with higher degrees of separation because a larger number of alternative practices can be proposed by designers, accepted by clients, and trialled by users. However, once these stakeholders have experienced the full consequences of any given innovative sustainable practice, lower degrees of social separation may be more appropriate in order to diffuse the most efficient ideas to a larger population and ensure its continuous implementation in the future by reinforcing it as part of that society's culture.

5. Discussion

This paper has addressed a key aspect that may importantly affect how new sustainable design solutions emerge in a social group and how they may ultimately impact and change existing ideas and practices in the future. Through a series of systematic studies of computational models, this research illustrates that the way in which a society is arranged can determine the success or failure of an innovation. This is a significant finding given that innovation is often explained in simplistic terms placing causality on the advantages of the new idea or the talents of its promoters, i.e. "a new solution will be adopted simply because it is better". This is an overly simplified assumption that often goes against actual cases of innovations. Studies of change agency in social simulations are able to show that seemingly secondary or passive contextual issues can play an active role in innovation in a complex system where interactions and situational characteristics can have unexpected effects in the success or failure of a new idea.

We have explored through equivalent computational simulations a separate range of issues that can further contribute to understand the role of designers as change agents. Due to the scope of this paper, they are included in order to illustrate other types of variables considered in these studies:

- Type and strength of social ties between members of a social group. Namely, the length of time that agents in a society are likely to maintain their relationships with other agents over a time span. Our results show that varying strengths of ties causes changes in the likelihood of a society to generate and accept innovations. This is explained by a process of hierarchy formation of influence between adopters which supports different levels of authority and conformity [7]. Sustainable design practices may benefit from weak ties at a nascent stage when low levels of authority facilitate acceptance by early adopters, and they may benefit from strong ties at later stages in order for them to reach a large number of late adopters [1].
- Emergence of lever points or 'tipping points' that represent the stage at which the growth of adoption of a new idea is sustained by the diffusion process itself independently of any external intervention. Our models confirm the idea that the tipping point can occur at different stages of diffusion of a new idea. It may appear early or late; it may cause a rapid acceptance or a rapid rejection of a new idea, or it may be an opportunistic combination of two previous competing ideas [7, 15].
- Types of features of new ideas and their effects in diffusion. Namely, some features that our simulations have shown to facilitate social change include:
    - new values or ideas that are more ambiguous or open to reinterpretation by stakeholders, are more likely to be spread rapidly
    - new values or ideas that are less complex or can be transmitted more easily are more likely to reach a larger proportion of the population
    - new values or ideas that are more compatible with existing wide-spread values or with other competing new values, are more likely to be accepted by groups of evaluators that would otherwise find it difficult to agree or converge [7].

Further details and a more detailed discussion of these phenomena can be found elsewhere [7]. However, more work is required to develop a more complete picture of the types and levels of variables that could determine the emergence and fate of new ideas in complex systems. Computational modelling is required to further explore these variables as well as the possible interaction between variables. For instance, it is still unknown how could the effects of field, domain and individual variables interact with each other in a complex social system. Future research should aim to move from explorative simulation into validating results against laboratory and field experimentation.

Scale is a key factor that deserves further attention in order to facilitate experimentation outside computational models. It is unrealistic to assume that a structural variable such as degree of separation can be manipulated in a society and guarantee that all other conditions are kept constant. Nonetheless, this seems feasible in small groups and teams either in laboratory or field settings where the researcher has a higher degree of control over experimental variables. Moreover, further work is needed to assess the variation in scope and rate of diffusion in real cases to confirm whether the degree of separation may be sufficient to determine the adoption of novel ideas.

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