SYSTEM INNOVATION FOR SUSTAINABILITY AT PRODUCT DEVELOPMENT LEVEL: A CONCEPTUAL FRAMEWORK

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Abstract

It is now commonly accepted that, in order to achieve sustainability, the socio-technical systems which fulfil social functions such as housing, food, mobility need to be transformed. This transformation is known as system innovation and requires multi-scale and systemic approaches to innovation. The literature on system innovation has provided explanations regarding how companies and product development activities fit into the big and long-term picture of system innovation only to a certain extent and this area remains largely neglected in the literature. In order to address this gap, this paper presents a conceptual framework explaining how innovation efforts at the micro-level (i.e. product/service development) can systemically be aligned with those efforts at the macro-level (i.e. socio-technical systems). The framework is prescriptive and states that companies are part of society and thus, their strategic goals should not be contradictory to visions of society and these goals should be aligned with the goals of the society envisioned to achieve sustainability. This requires companies to acknowledge the long-term visions of the society during their strategy development to guide their decisions on product development.

Keywords: system innovation, sustainability, product development, product design

1. INTRODUCTION

Sustainability is a system property and not a property of system elements (Clayton and Radcliffe, 1996). As the discourse on sustainability matured over the past twenty years, our understanding of the concept has evolved from being an idealized, generalized and static property of individual (system) elements to contextual and dynamic properties of systems themselves (Faber, Jorna, & Van Engelen, 2005). This dynamic conceptualization of sustainability assumes both internal and external changes will occur over time and space, thus, posits sustainability as a 'moving target' (Hjorth & Bagheri, 2006, p. 76). Internal and external forces influencing change over the environment, society and economy continuously alter the conditions of sustainability. Since sustainability is a moving target, it needs to be planned through process-based, multi-scale and systemic approaches, which are guided by targets/visions, instead of traditional goal-based optimization approaches (Bagheri & Hjorth, 2007).

Since sustainability is a dynamic system property, products, services, technologies and organizations cannot be regarded as sustainable on their own right but they may be elements of sustainable socio-technical systems. The requirement for dematerialization of production and consumption and the needed decreases in greenhouse gas emissions are not likely to happen through the current technological path (Rennings, 2000; Jansen, 2003; Ryan, 2008a). It is now commonly accepted that, in order to achieve sustainability, there is a requirement for transformation of socio-technical systems. Therefore, since solely product-centered design and development approaches generally result in incremental improvements (see Brezet, 1997 for a typology of product development approaches compared to their sustainability gains) and a need for adopting a systemic approach, the discourse on innovation for sustainability has shifted from company-level processes to wider and linked processes at the socio-technical system level within which needs for housing, mobility, food, communications, etc. are satisfied (Smith, Stirling & Berkhout, 2005).

The needed transformations at socio-technical level covers institutional, social/cultural, organizational as well as technological change (Loorbach, 2010); that is, they need to take place at societal level. The process of societal transformation which needs to take place to achieve sustainability is defined as the transition to sustainable socio-technical systems or system innovation for sustainability.

Companies are important actors in this transformation and will have important roles in developing the technologies of the new system (Charter et al., 2008). Even though theory around system innovation is now very elaborate, it provided explanations regarding how companies and product development activities fit into the big and long-term picture of system innovation only to a certain extent. Recent contributions articulated different perspectives on system innovation including business perspective, design perspective and consumer perspective through cases, examples, and some models (e.g. Tukker, et al., 2008; Van Bakel et al., 2007). However, there is a lack of theory on how micro and meso-level changes (organizational and technological changes in companies) can and should be aligned with the macro-level (institutional and social/cultural changes in the wider society) changes.

In order to address this gap, this paper proposes a conceptual framework explaining how wider-scale systemic changes can be addressed at company and product development level. The conceptual framework is developed by integrating insights from sustainability science, complex adaptive systems theory and the newly emerging system innovation theory. The next section presents a summary of these insights upon which the conceptual framework is established. Third section presents the conceptual framework. The implications of the framework for policy makers, companies, educators and professionals working in the product development area are discussed in the final section.

2. THEORETICAL UNDERPINNINGS

2.1. Complexity and Co-evolution

Socio-technical systems are complex (adaptive) systems. The major characteristics of complex systems are identified as unpredictable behaviour, large number of components with many interactions among them, decentralised decision-making and limited or no decomposability (Casti, 1986). A complex system has intricate sets of non-linear feed-back loops so that it can only be partially analysed at a time. Socio-technical systems show emergent properties. In emerging complex systems there is continuous novelty and these systems cannot be fully explained mechanistically or functionally since some of their elements possess individuality, intention, purpose, foresight and values (Funtowicz & Ravetz, 1994). Complex systems cannot be fragmented without losing their identities and purposefulness (Hjorth & Bagheri, 2006; Linstone, 1999) state that. In addition to irreducibility and emergent behaviour, the other characteristics of complex systems are self-organisation, continuous change, sensitivity to initial conditions, learning, irreducible uncertainty, and contextuality (Cilliers, 1998; Gallopín, Funtowicz, O'Connor & Ravetz, 2001; Manson, 2001; Cooke-Davies, Cicmil, Crawford & Richardson, 2007). Complex systems in general are hierarchic or have multiple-levels and each element is a subsystem and each system is part of a bigger system (Casti, 1986; Gallopín et al. 2001; Holling, 2001; Gallopín, 2004). Hierarchical structures have adaptive significance (Simon, 1974). This adaptive significance is not due to a top-down authoritative control but rather due to the formation of semi-autonomous levels which interact with each other and pass on material and/or information to the higher and slower levels (Holling, 2001). For an effective analysis of a complex system, the analyst needs to oversee the (sub)system being analysed from a vantage point. This vantage point should be at a higher or preferably meta-level to identify a context specific perspective while still acknowledging the interconnections between the (subsystem) being analysed and the rest (Espinosa, Harnden & Walker, 2008). It is not possible to study complex systems meaningfully by breaking them into their components. At times when there is a need to define system boundaries, this should be done acknowledging how the part under study relates to the rest of the system.

The distinguishing feature of complex adaptive systems is that ‘they interact with their environment and change in response to a change (Clayton & Radcliffe, 1996, p.23)’. They are resilient; therefore, they ‘can tolerate certain levels of stress or degradation (p. 31)’. As a result, sustainability of a CAS can be achieved if the adaptive capacity of it is not destroyed. The subsystems of a system should be adaptable to changes which occur both in the other subsystems, and as a result, in the entire system. The subsystems must co-evolve to render sustainability possible. Co-evolution refers to the mutual change of all system components. During this mutual change, one component may or may not dictate a change over other(s).

2.2. Operational Time-Frame

Even though the length of time frame to be used when planning for sustainability is still being debated, the concept intrinsically requires a long-term future orientation. Long term is not a static, predetermined time span to be applied to the whole of the meta-system. Rather, it is determined in line with the nominal temporal (and also spatial) scales of the system component whose sustainability is of concern (Costanza & Patten, 1995). For cities, for example, the nominal life span can be accepted to be 1000 years or more. However, for a human being, the nominal life span, and hence the 'long term' in which sustainability is monitored and assessed will be around 70 years.

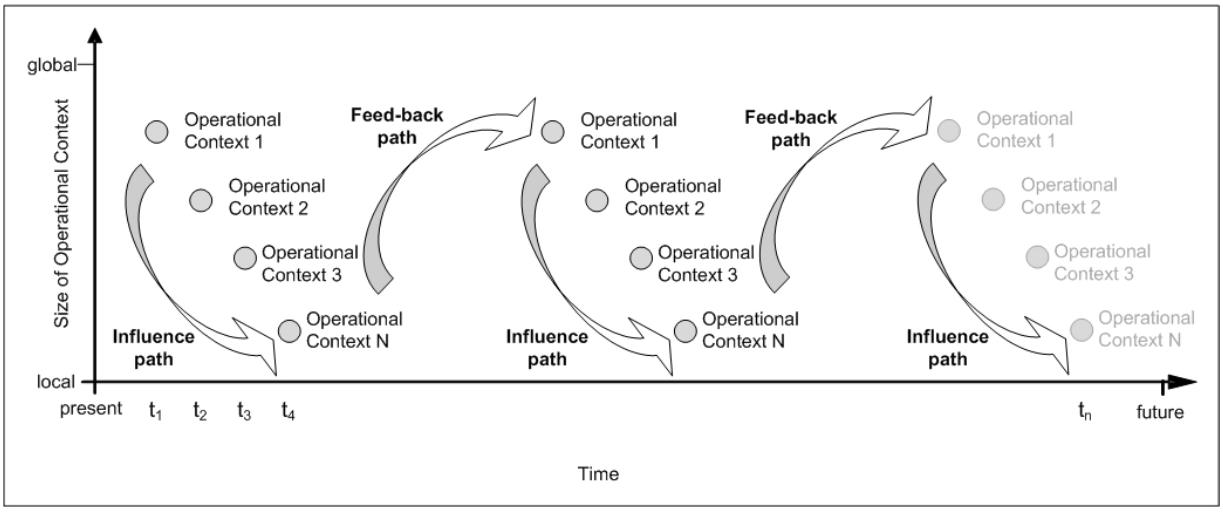

Figure 1: Temporal and spatial scale versus size of the operational context (adapted from Gaziulusoy & Boyle, 2008)

When sustainability of a complex system is of concern, from smaller (smallest) to broader (broadest), there is a continuum of hierarchically interdependent operational contexts to which the concept of sustainability can be applied (Figure 1). According to the operational context, the length of 'long term' should change; as the operational context widens, the length of planning should extend in order to cover subsumed operational contexts and to connect them both spatially and temporally (Gaziulusoy & Boyle, 2008). Nevertheless, this is not a one-way linear relationship. While planning at higher-order operational contexts requires longer and wider scales to cover lower-order contexts, lower-order contexts are externally bound by this larger scale no matter what their internal scale is (Holling, 2001). As an illustrative example, climate and vegetation can be considered. Climatic cycles are much longer than vegetation cycles.

Successive generations of the same type of vegetation are dependent on annual rainfall and temperature. In accordance with the resilience of vegetation, variations in rainfall or temperature between years are tolerable to some extent. But as climatic change affects the rainfall or temperature over the long term, first, some characteristics of the vegetation and then the type of vegetation will need to change. This also applies to human-nature interactions, as the previous example could easily be adapted, for example, to agriculture-climate or technology-resource cases. Therefore, lower-order operational contexts should be aware of issues and scales of higher-order operational contexts, first, to guarantee their success and, second, to guarantee sustainability of higher-order contexts.

2.3. Co-evolving Contexts of Change in Socio-technical Systems

For a better understanding of influencing system innovation for sustainability at product development level, there is indeed a need for analysing the dynamics of co-evolutionary influence patterns relevant to product development within the socio-technical system. In general, society and technology shape each other on an ongoing and bilateral basis (Geels, 2005a, 2005b); i.e. they co-evolve. Institutional and social/cultural changes generally take place before and, consequently, influence organisational and technological changes (Freeman, 1992). In general, institutional and social/cultural changes are more fundamental and powerful than organisational and technological changes. For example, science and research policy determines the direction of investment and thus influences technological change along that direction. Similarly, international laws and agreements determine the characteristics of international trade unions. Societal norms and values determine, to a large extent, how social organisation is structured.

Figure 2 shows some of the different elements of socio-technical system influencing technological change on a co-evolutionary basis. These elements are grouped under four types of socio-technical system component: institutional, social/cultural, organisational and technological. For example, user/consumer is a small-scale, social/cultural-type element while infrastructure is a large-scale, technological-type element. The circular arrows in the figure indicate that the change is continuous and dynamic, and, every element influences each other.

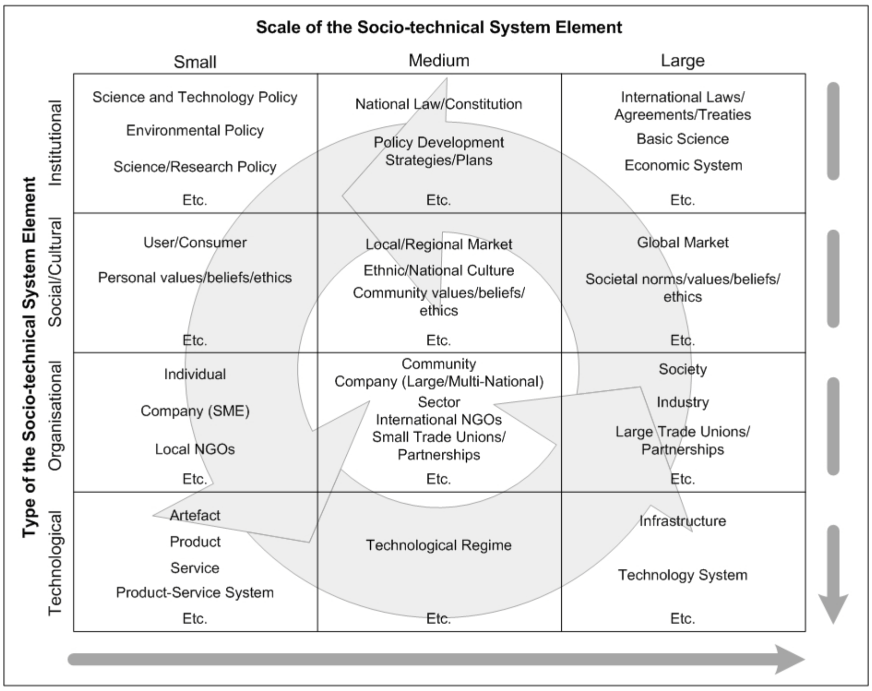

Figure 2. Co-evolutionary dynamics within the socio-technical system

Despite the hardship associated with analysing the dynamics between different types of the socio-technical system components, there are easily observable patterns between different scales of them. Complexity increases as the scale becomes larger. Consequently, as the scale gets larger, managing change becomes harder and the pace of change gets slower. Also, smaller scales of one type of socio-technical system component are hierarchically dependent on larger scales of the same type. For example, products are determined by the relevant technological regimes and the technological regimes are determined by the technology system. Similarly, change in the large scale of a particular type of socio-technical system component is likely to require change in smaller scales of the same type. Nevertheless, smaller scale socio-technical system components may or may not induce/influence change in the larger scales of the same component.

2.4. Product Development Perspective: Levels of Innovation for Sustainability

Brezet (1997) defined four levels of innovation for sustainability (Figure 3). The first level is product improvement. Product improvements are focused on reducing environmental impacts for existing products. The second level is product redesign. In product redesign, product concept remains almost intact but either the product or its components are further developed or replaced. The first and second levels are where most of the efforts are focused at the moment, driven mainly by the regulatory push/push mechanisms. These first two levels have a product focus and are performed within the realm of established technologies and social uptake of established technologies. The third level is function innovation. At this level, the innovation is not limited to existing product concepts but related to how the function is achieved. This level generally constitutes a transition between product focus and system focus. The fourth and final level of innovation defined by Brezet (1997) is system innovation. At this level, the whole technology system is replaced by a new system.

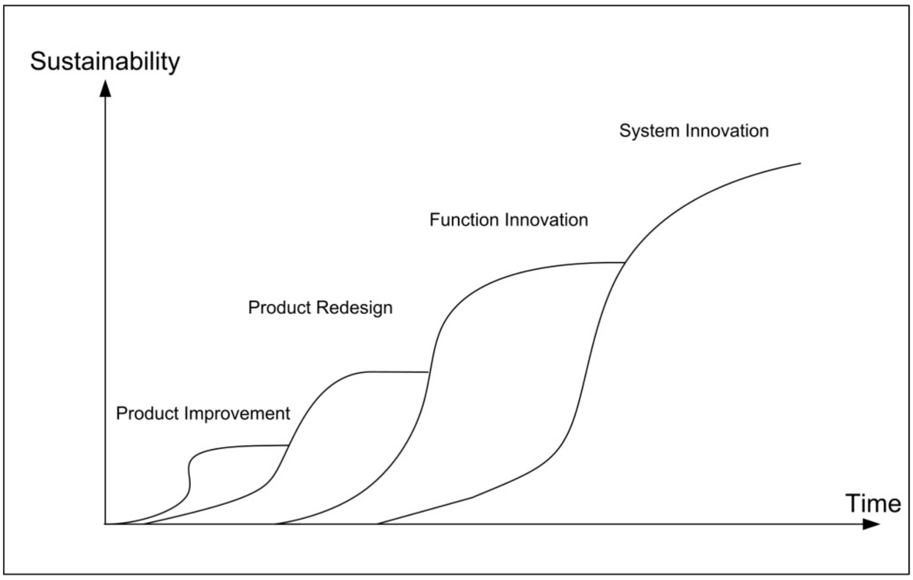

Figure 3. Levels of innovation for sustainability (based on Brezet (1997))

3. The Conceptual framework

3.1. Combining Levels of Innovation, Co-evolutionary Dynamics and Time-frame

One particular challenge in linking activities of product development teams to system level innovation becomes evident when the socio-technical contexts of change required to be intervened at each level of innovation are considered (Figure 4). Towards the upper levels of innovation for sustainability, the complexity of the problem increases because the context of change required widens. At the first two levels, a company is a sufficient entity for analysis and action. However, towards upper levels the change requires the collaboration of many stakeholders, some of which are not recognised as stakeholders currently. For the system level innovation to take place there is a need for change at institutional level, i.e. at the very fundamentals of society including norms, values, socio-cultural practices, and the underlying assumptions of the economic system, as well as organisational and technological change. As a result, in planning for system innovation for sustainability, companies and product development teams face a challenge which is not comparable in scale to any previous challenges the industry has faced. On the one hand and in the short term, companies have to design/redesign products to meet immediate business priorities like decreasing the cost and time-to-market while assuring quality, market appeal, competitiveness, and compliance to ever-toughening legislation and standards. On the other hand, in addition to these generic and short-term business goals, they should develop new technologies in the medium and long term which will overcome the burden put by the prevailing production-consumption patterns on the environment and society.

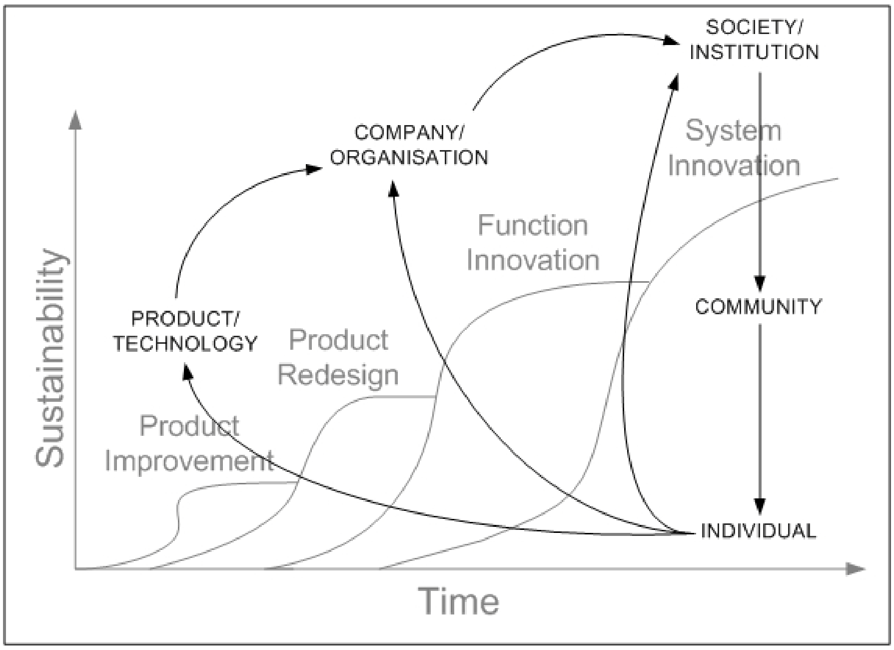

Figure 4. The contexts of change in relation to levels of innovation for sustainability

Another challenge in linking activities of product development teams to system innovation is related to the associated time frames. System innovation requires long-term planning (i.e. 50 years or more) due to the complexity embedded both in natural and social systems and the dynamic nature of sustainability requirements. The time frames required for system innovation are far beyond the ones usually used by companies for planning (Jansen, 2003). Nevertheless, system innovation assumes that structural changes will take place in the socio-technical system including the major assumptions of the current economic system and the role and responsibilities of businesses within society. Therefore, there is a need to mediate the time-frames required for system innovation with those used by companies and product development teams.

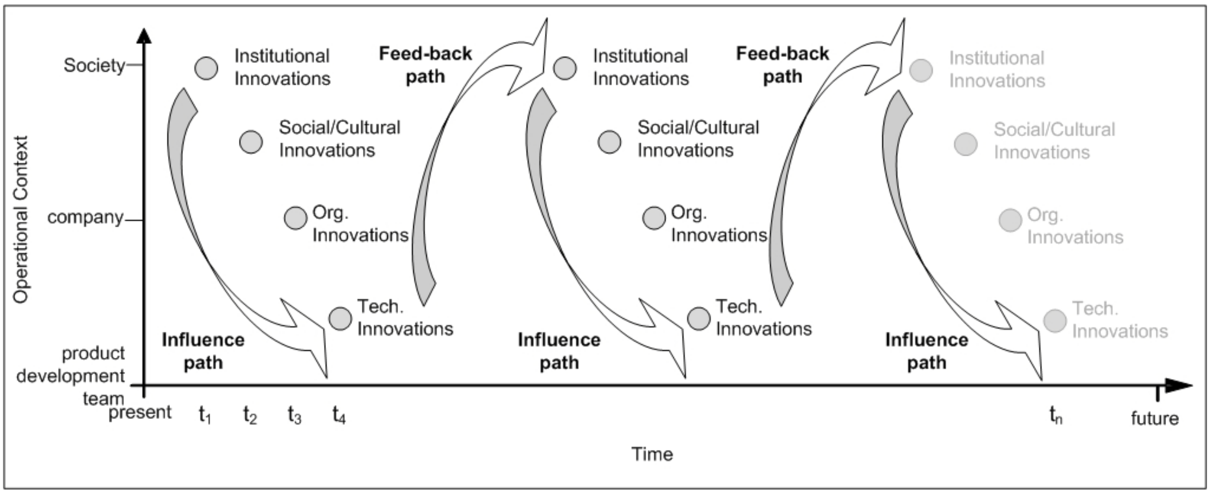

Figure 5. Temporal and spatial positioning of relevant types of innovation

Referring back to the discussion about the operational time frames, as the operational context widens, the length of planning should extend in order to cover subsumed operational contexts and to connect them both spatially and temporally. In Section 2.3, it was stated that social and institutional innovations will influence organizational and technological innovations and then will be influenced by new organizational structures and technologies in a recurring manner. Therefore, based on a systemic hierarchy, society is the widest operational context relevant to system level innovation followed by the company and the product development team. Figure 5 temporally and spatially positions types of innovation relevant for different operational contexts and relevant types of innovation based on the operational time frame model (Figure 1). According to this positioning, institutional and social/cultural innovations should be subjected to the longest planning period followed by organizational and technological innovations. There will be feedback paths established from smaller-scale, shorter-term innovations informing both each other and innovations taking place at longer time spans and in wider operational contexts as the implementation progresses.

Figure 6 combines the levels of innovation (Figure 3) and the different scales of socio-technical system components (Figure 2) in order to link system innovation to the activities of product development teams in a meaningful way. Since innovation is systemic and product development is indeed a component of another system, the activities taking place at the product development level has to be considered in the context of the company. Therefore, the product development function needs to be systemically positioned in the company, and the company needs to be systemically positioned in the society. In order to achieve this, the time frames applicable to the three operational contexts (i.e. society, company and product development) and the mechanisms of aligning the activities of product development to the transformation which needs to take place in the wider society to achieve sustainability needs to be clarified.

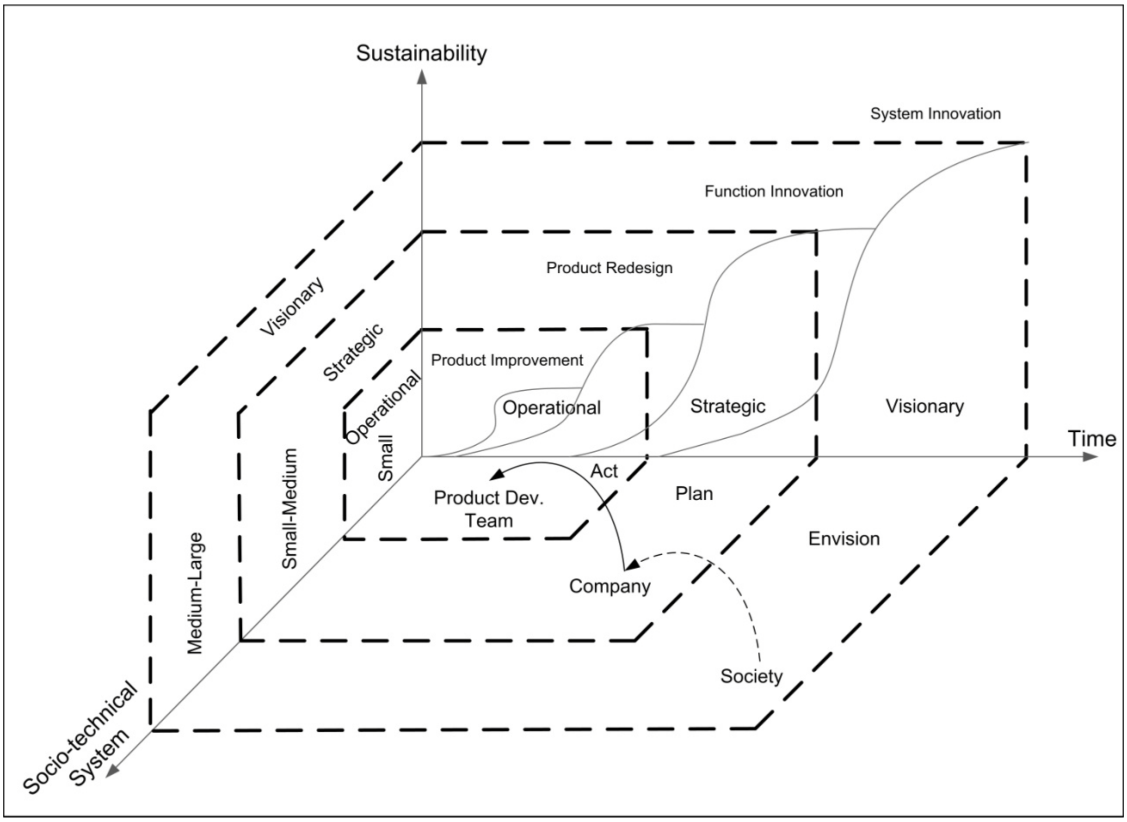

Figure 6. A model to link product development function to system level innovation

As shown in Figure 6, the planning periods applicable to the levels of innovation can be defined as operational in the short term, strategic in the medium term and visionary in the long term. The short term used here covers ten years which is the longest business planning period for most companies. It is acknowledged that there are indeed shorter periods that businesses need to make decisions and take action within, such as daily, monthly or annual periods. In addition, product development cycles are getting shorter as the global competition increases and lean product development practices become more widespread. Nevertheless, it is empirically proven that as the complexity and innovative content of products increases the development cycle becomes longer (Griffin, 1997a, 1997b). In cases of radical innovation, the technological and market uncertainties require longer learning periods, and therefore, more time needs to be invested (Herrmann, Gassmann & Eisert, 2007). Case studies (e.g. Lynn et al., 1996; Veryzer Jr., 1998; Abetti, 2000) have shown that for radical innovations, time-to-market cycles as long as and sometimes longer than ten years is common.

The strategic period should shape the operational period through the setting of goals at the organisational (company) level. Individual companies have very limited ability to influence change at the larger components of the socio-technical system, i.e. institutional, social/cultural, especially in the short-term. Nevertheless, it should be emphasised once again that companies are part of society and thus, even though they fall into small/medium scale within the socio-technical system, their strategic goals should not be contradictory to visions of society. On the contrary, their strategic goals should be aligned with the meta-goals desired at societal level to achieve sustainability. In order to achieve this alignment the planning periods applicable to companies (operational and strategic) need to be linked to the long-term planning period; theoretically, at the end of the long-term planning period the whole socio-technical system should have been transformed. Therefore, companies should acknowledge the long-term visions of the society during their strategy development which then will guide the product development decisions.

3.2. Social Function Fulfilment, System Innovation and Product Development

Socio-technical systems are defined by the social function fulfilled by them (Geels, 2004); such as housing, mobility and energy. In planning for system innovation for sustainability, focusing on social function fulfilment broadens the thinking which was previously limited to material and technical aspects of cultural, behavioural and organisational domains of innovation, and therefore, provides more leverage points to influence the system change (Ryan, 2008b).

From the perspective of product development, innovating to find alternative ways of fulfilling a social function is not a novel concept. Indeed, this is one of the main strategies applied by product designers/developers in new product/service development. However, social function fulfilment, as currently understood from the perspective of product design/development, corresponds to the third level of innovation for sustainability (see Section 2.4). Therefore, it does not consider social/cultural and institutional innovations which are essential to achieve innovation at system level as leverage points to focus on in product development.

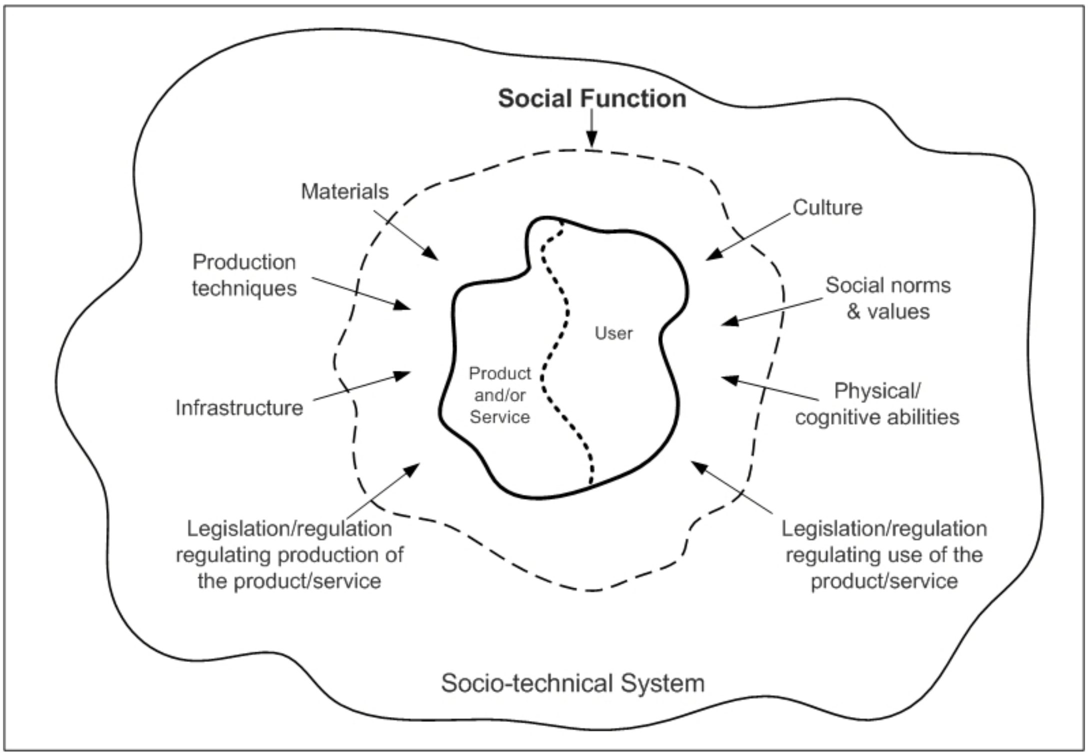

Figure 7. A model for social function fulfilment at product development level

Figure 7 is a model to describe social function fulfilment from the perspective of product development with a systemic understanding. The model conceptualises social function fulfilment in the wider context of the socio-technical system. As stated before, a socio-technical system has institutional, social/cultural, organisational and technological components. Social function cannot solely be described technologically but needs to be referenced to the other components of the socio-technical system as well. Fulfilling a social function requires consideration of several -institutional, social/cultural, organisational as well as technological- variables simultaneously. These variables include materials, production techniques, infrastructure, culture, social norms/values, cognitive/physical abilities of the user and legislation/regulation which govern the production and use of a product/service. These variables all together determine the conditions and limits of fulfilling that social function within the socio-technical system of concern. In this systemic approach to conceptualising social function fulfilment, these variables are co-dependent. Each of them is subject to change during the systemic transformation towards sustainability. Therefore, they need to be acknowledged individually yet considered simultaneously in system innovation as complementary to each other. It should be noted that the size of the physical variables (materials, infrastructure) may vary independently of the social function since a function can be met in multiple ways some of which may be more material intensive than the others.

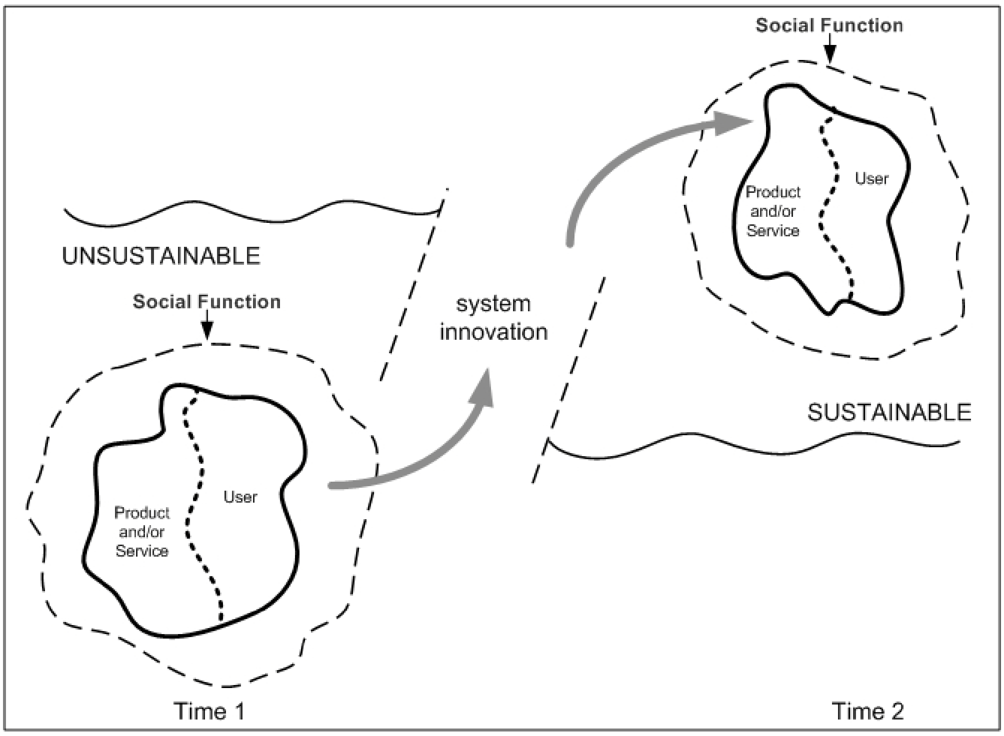

Figure 8. System innovation model from the perspective of product development

System innovation should enable fulfilment of the same social function in the future through a combination of innovations in institutional, social/cultural, organisational as well as technological contexts of the socio-technical system. From the perspective of product development this means adopting a proactive and systemic approach in design and development of the products/services by taking both physical and non-physical variables, which can be influenced at the product development phase, into consideration. Figure 8 provides a model to explain system innovation from the perspective of product development. According to this model, if in developing alternatives to fulfil a particular social function, the physical (e.g. materials, infrastructure, and production techniques) and non-physical (e.g. regulations, social norms and values, cognitive abilities of the user(s)) variables are considered and leveraged simultaneously, system level innovation can be influenced through activities and decisions at the product development level. If institutional, social/cultural, organisational and technological determinants of a social function are considered simultaneously, neither the capacity and characteristics of present technologies nor the expectations of present market and user becomes a focal point around which innovation will shape. Instead, the focal point becomes the social function to be fulfilled. This way, possible combinations of physical and non-physical variables together enabling that function to be fulfilled can be conceived. As a result, product development can have a proactive role to play in much wider and longer-term changes which need to happen at institutional and social/cultural levels.

4. CLOSURE

Sustainability is a system property and multi-scale and systemic approaches. These approaches should be guided by targets/visions, instead of traditional goal-based optimization approaches. Since sustainability is a dynamic system property, the discourse on innovation for sustainability is shifting from focusing on individual products, services and technologies to entire socio technical systems which fulfil certain social functions such as housing, mobility, food etc. At an organisational level, this shift implies a shift from company-level processes to wider and linked processes at the socio-technical system level. The theory around system innovation has provided explanations regarding how companies and product development activities fit into the broader picture of system innovation only to a certain extent and the topic is highly neglected in the literature.

In order to address this issue, this paper presented a conceptual framework explaining how innovation efforts at the micro-level (i.e. product/service development) can systemically be aligned with those efforts at the macro-level (i.e. socio-technical systems). The conceptual framework is developed through integrating insights from sustainability science, complex adaptive systems theory and system innovation theory. The conceptual framework contributes to the main body of system innovation theory by building on it to specifically address product development level in system innovation for sustainability. The framework is prescriptive and states that companies are part of society and thus, their strategic goals should not be contradictory to visions of society and these goals should be aligned with the goals of the society envisioned to achieve sustainability. This requires companies to acknowledge the long-term visions of the society during their strategy development to guide their decisions on product development.

Acknowledgements

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