Nurturing Sustainability at the Roots- During Conceptual Design

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Having worked as a hands-on design engineer for decades along with academic research on Design Theory and Methodology, the author was inspired to look into the possibility of applying some of the concepts from the field to contribute to improved sustainable development. This article is a result of that endeavour. There are better chances that sustainability is achieved if the relevant factors are imbibed in the initial stages of the design process itself just as the laws of physics, aesthetics, functional requirements and many such aspects are considered compulsorily as an inherent part of the design methodology. The article proposes an integrated approach to include identification of sustainability parameters and their consideration in the multi-phase design mapping process. Further, consideration of entropy as a common measure across different fields pertaining to technology as well as pillars of sustainability namely environmental, economic, and social appears to be promising. Finally, as an example, the article looks into factors pertaining to sustainability considering outsourcing business model where teleoperation and telepresence technologies are expected to play enhanced roles.

Keywords: Sustainability, Entropy, Design Theory and Methodology, Conceptual Design, Business Methods, Outsourcing, Teleoperation, Telepresence

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1. INTRODUCTION

While UN's Millennium Development Goals transit to Sustainable Development goals (Hsu et al., 2014) with stress on integrated approach (Secretary-General's High-level Panel on Global Sustainability, 2012) considering the well-recognised three pillars of sustainability (Hasna, 2007)- environmental, economic, and social (under debate to include political and cultural aspects); the question has remained: what can be the technological tools or methodologies that may be employed to ensure the same? It has been rightly highlighted (Smith, 2012) that the thinly stretched scientific community may not be able to support a new assessment process and further questioned whether that is what policy makers really need from research? Kareiva (Kareiva, 2014, Ehrlich et al., 2012) has expressed that as one of the 21st century's wicked problems, need for sustainability may have some solutions in the perceived magic of science or beyond but no university, NGO or government agency can have the practical answers alone without solving them at the incubation stage bringing resources and people together shedding their biases. While sustainability index and indicators (Bell et al., 2008, Scerri et al., 2010) are efforts to measure the level of sustainability when a system or process is already in practice, it is often too late or too costly to go back to the origins to improve the resultant performance. Here, the author proposes that there is a means to integrate the basic tenets pertaining to sustainability at its origins- where it all starts: during the earliest conceptualization stages of a product or process design, minimizing influences of subjective or biased decisions. The paper is organised as follows. Section 2 presents the proposed approach as an extension of the state-of-the-art in Design Theory and Methodology considering entropy and sustainability. Section 3 discusses application of the proposed approach considering Teleoperation and Telepresence as examples.

2. PROPOSED APPROACH

Ever since about last 50 years of research in the relatively new field of Design Theory and Methodology (which has its origin sometime between the first conference on Design Methods at Imperial College London in 1962 and consequent founding of Design Research Society in 1966), the effort of scientists and engineers has been to make the process of design as objective and systematic as possible (Pahl et al., 1988; Hubka et al., 1988; Suh, 2010; Naidu et al., 1997; Blessing et al., 2014). The role of design process in achieving sustainability is emerging only recently (Walker, 2006). Based on Shannon's mathematical

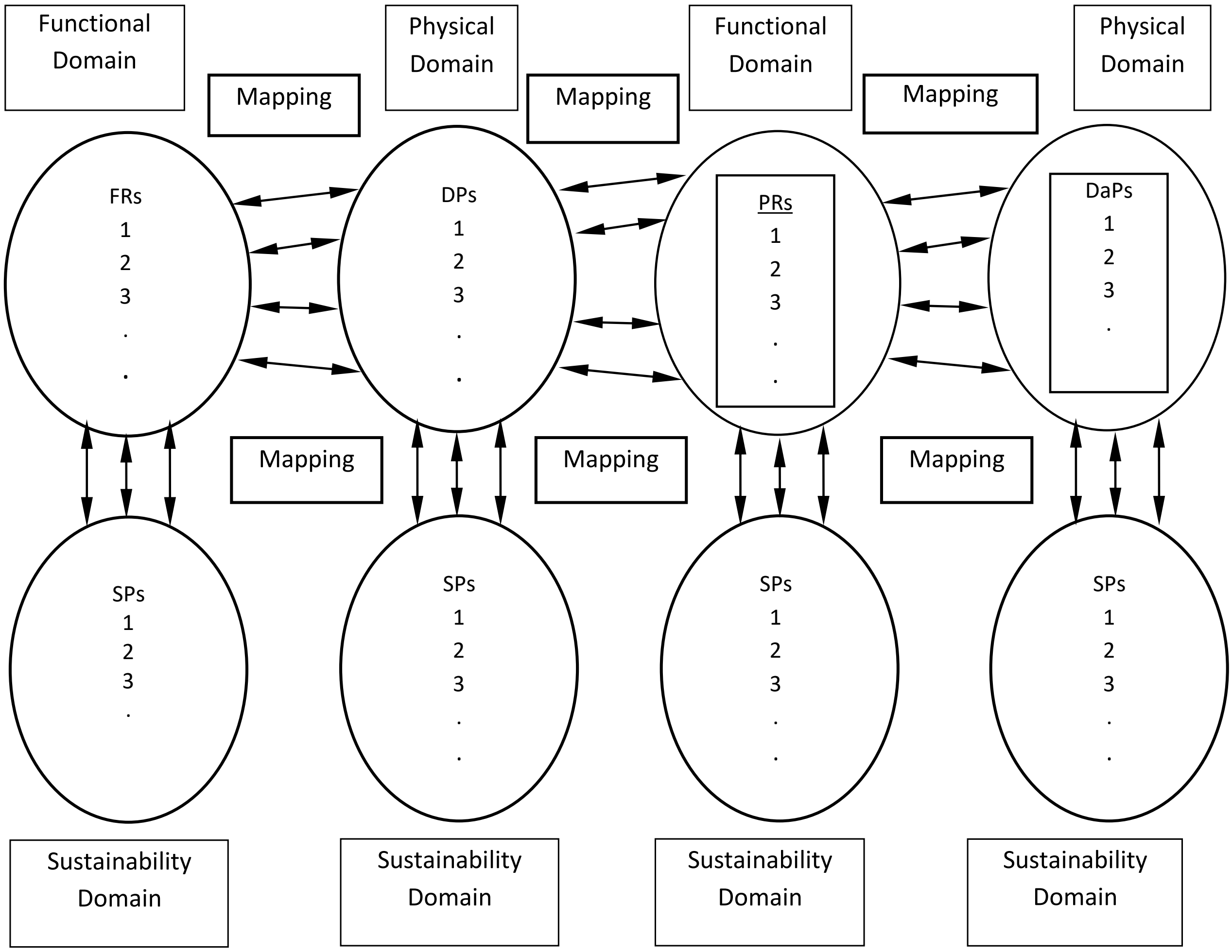

FIGURE 1. Conceptual design mapping including sustainability domain. [Legend; FR: Functional Requirement, DP: Design Parameter, PR: Process Requirement, DaP: Design Automation Parameter, SP: Sustainability Parameter]

theory of communication (Shannon, 1948), while the metric of entropy is not new to design theory (Suh, 2010; Naidu et al., 1997) and sustainability (Pascale, 2012; GoBling, 2001; Krysiak, 2006; Penner, 2007) researchers in isolation from each other, the author proposes its deployment as an integrated step during early conceptualization for sustainability. The power of this approach derives from the fact that entropy can be a measure for several parameters having diverse origins including but not limited to environmental, economic, social and technological. Entropy is broadly a measure of disorderliness that is considered as always increasing for a closed system based on the well laid down physical laws of thermodynamics (Bailey, 2010). Entropy has also been associated with complexity theory (Menhorn et al., 2011) giving hope that it can probably have a solution for some of the difficult problems confronting us, sustainability being one of them, particularly as it spans across different disciplines as diverse as basic science, engineering, business, social sciences and humanities. Shannon entropy of a finite sample x1, x2, x3,. . . , xi ,. . . , xn of a random variable X is expressed as,

$$E[I(X)] = E[-log(P(X))] = \sum_{i=1}^{n} p(x_i)log(p(x_i))$$

wherein, measure of Entropy (E) associated with information (I) of the variable (X) is the negative of the logarithm of the probability mass function. The implication of this is the more certain an event, the less information its occurrence adds to our understanding of the underlying process.

3. APPLICATION EXAMPLES

Let us consider teleoperation (Kim et al., 2004) and telepresence (Kammerl and Steinbach, 2010) systems as examples. While teleoperation is conducting a task at one location through control of the actions

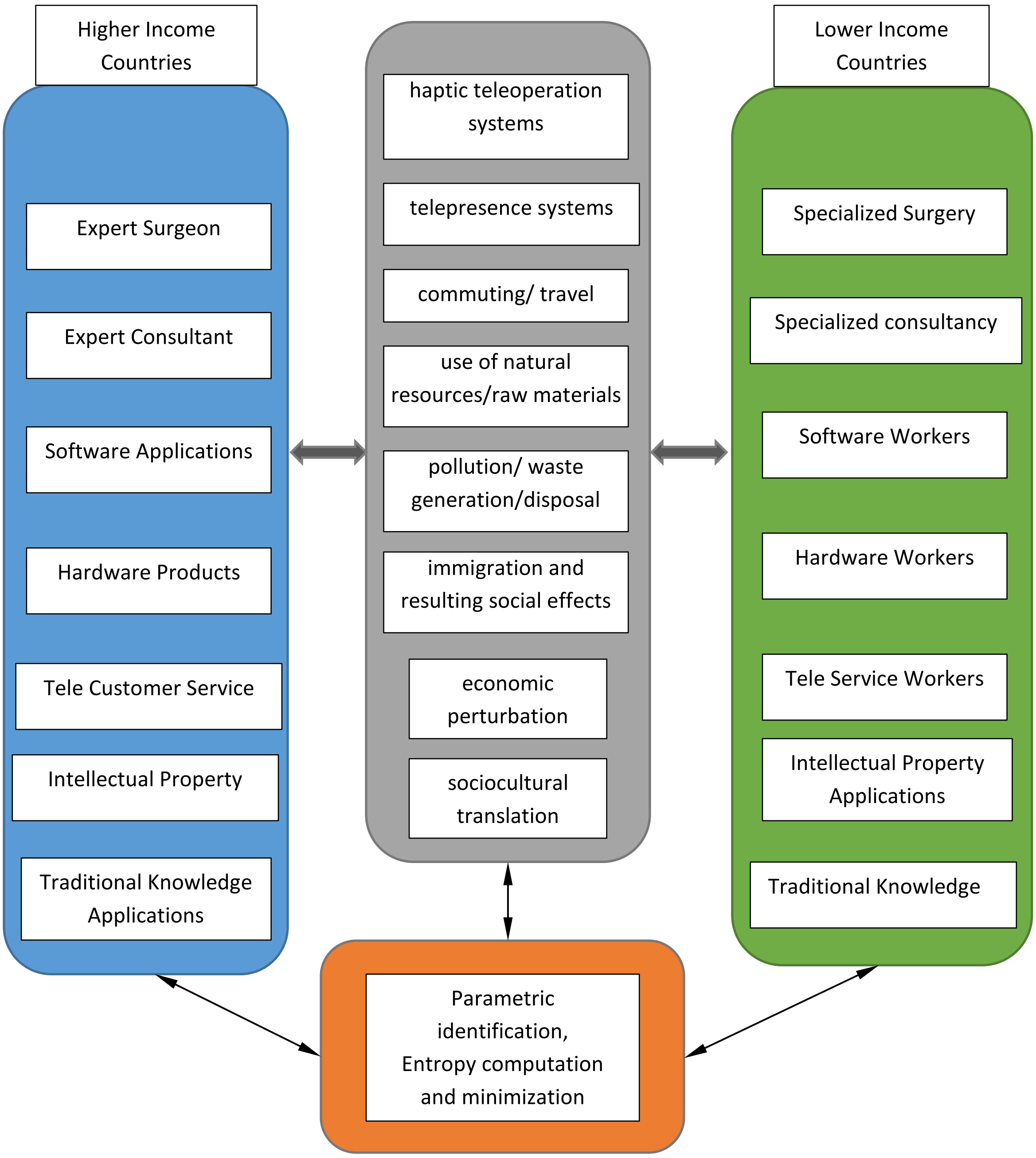

FIGURE 2. Example illustrating sustainability influencing factors in outsourcing business model

from a different location, telepresence is a virtual proximity through audio communication, 2D graphic or 3D holographic representation of a person physically present at a different location. Both the technologies have seen growth in the recent years which is expected to continue, although the full potential of teleoperation applications is yet to be realized due mainly to very high capital equipment cost associated with safety considerations and complexity of some of the areas such as space exploration, remote surgery and hazardous material handling which have been early adopters of the technology because of pressing and inevitable need coupled with high investment of funds in some of these fields. Telepresence, through the fairly matured and well established telecommunication technology enhanced by recent enablement of free or low cost video conferencing means is perhaps the most widespread application that has become possible by advancement in internet as well as mobile phone networks' capacity and affordability. An important element of some of the more advanced teleoperation systems is a haptic (Kim et al., 2004) device which enables a controller master to sense the forces effected at the slave side. Although haptic devices have recently become quite low cost by developed countries' affordability standards, they are still substantial (£2500 and above) but may inevitably come down with new applications driven by both market pull and technology push as has happened in the case of many other gadgets. As teleoperation and telepresence systems are expected to permeate further into daily lives, with ubiquitous haptics (Sekiguchi et al., 2005; Cheng, 2014) and newly emerging field called haptography (Elgan, 2014; Kuchenbecker, 2014) probably becoming a widespread reality in future, it is imperative that their implementation is evaluated at the conceptual design stages of products, processes and business methods with appropriate considerations of overall sustainable development (Figure 1).

After the design mapping stages are completed following the considerations of coupled, decoupled or uncoupled designs (Suh, 2010; Naidu et al., 1997), the competing concepts need to be evaluated for minimum information or entropy content. With the inclusion of sustainability parameters related to environmental, economic, and social factors, it is possible to ascertain which conceptual design option would be more favourable to sustainable development. It is significant to note that the entropy minimization of the elements of a teleoperation system such as haptic device through method of entropy coding (Kammerl, 2012) is only a small part of the total entropy of a sustainable system design. The author calls this segment as device entropy, as entropy coding is a technique in which haptic data reduction is achieved by deploying Weber's law of Just Noticeable Differences (JND) and other sampling and quantization techniques to compress haptic data signals or reduce or even eliminate non-essential data. However, there are other segments of entropy such as behavioural entropy (Goodrich et al., 2004), entropy related to Coupled Human and Natural Systems (CHANS) (Mayer et al., 2014), and hitherto neglected aspects of teleoperation such as environmental, economic, and social impact which would need to be considered to improve sustainability.

Through an example of outsourcing business model in which both teleoperation and telepresence technologies are already playing considerable roles that are expected to enhance exponentially in future, Figure 2 introduces a basic overview to facilitate better appreciation of some of the critical factors, but much more would be needed to be researched to achieve increased sustainability through conceptual design framework in comprehensive but simple, practical and implementable terms so that it can permeate broadly across disciplines at the ground level. Our preliminary investigations indicate that there are interesting and promising insights that can potentially come out by the evaluation of sustainability factors at the conceptual design stages which may be generally ignored or oversighted in normal course of business decisions. For example, outsourcing need not be viable only from higher income country to lower income country as is traditionally thought of. It can be feasible even the other way round in fields such as teleoperation surgery provided that the entropy in the chain can be further reduced. Reduced entropy teleoperation systems also have the potential to open up new services in the developed world through remote providers in areas such as traditional knowledge applications. Public opinion against outsourcing in richer countries could be possibly pacified if the job losses can be shown by political establishments as compensated by reduced immigration coupled with creation of new opportunities provided by industries engaged in development of teleoperation and telepresence technologies, resulting in an overall reduction in entropy. Some of the questions pertaining to entropy reduction may be uncomfortable to answer, for example, reduction in global travel as well as local commute to work place that can be facilitated by teleoperation and telepresence technologies would cut down carbon footprint drastically, negatively affecting the passenger transportation and related industries. There are also technical challenges to reduce power consumption or to garner resources such as solar power to enable functioning of the teleoperation and telepresence technologies and also effective provisions for post-life disposal minimizing their environmental footprints too. Use of biodegradable materials such as bioplastics, aliphatic polyesters and new structural concepts to overcome the strength constraints would be the additional design challenges.

4. CONCLUSIONS

Conceptual design analyses considering sustainability can have broad and thought provoking repercussions on the way in which social and physical systems are perceived. It has the potential to lead to debates on the very notion of development in terms of market consumerism and affordability of goods in the name of higher living standards without ascertaining the sustainability factors. The agrarian societies which tend to be relatively more self-sustaining due to generally reduced entropy generation in biological processes- in fact negative entropy as Nobel laureate Schrödinger stated, are currently looked upon as under-developed, which may need a hard relook at perceptions. In the longer run, an informed and more objective design decision making at the conceptual stages keeping longer term sustainability factors in view would benefit the environments and societies which our future generations would inherit.

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Jyoti Prakash Naidu has worked in or has been affiliated with leading institutions, laboratories, and industry as well as start-ups and SMEs in the UK (University College London, University of Derby), USA (MIT-Spin-off Companies at Boston, University of Phoenix- Arizona), Canada (University of Toronto and Spin-offs, Meritus University, Carleton University), and India (Presidency University, MSRUAS, VTU affiliated institutions, CAIR-DRDO, IRIS, HMT) in different capacities. He has been recognized by several awards and honours including the Canadian Commonwealth Scholarship & Fellowship (1992-96), Defence Technology Spin-off Award received from the honourable Prime Minister of India as Project Director of Institute for Robotics and Intelligent Systems (2005), and National Mechanical Engineering Design Awards (Senior- 2003, Student- 1979) from National Design and Research Forum, Institution of Engineers, India; Canadian Star of Global Health Award (2013) from Grand Challenges Canada funded by the Government of Canada for Bold Ideas. He is the originator of the field of Design for Automation as an extension of the Axiomatic Design Theory established at MIT, and his research interests include Design Theory and Methodology with applications for Design of Intelligent Systems, Design for Patentability and Sustainability in the fields of medical devices, biotechnology, advanced manufacturing, mechatronics, robotics, automation, virtual reality, business methods and other areas overlapping with multi-disciplinary aspects of humanities and social sciences. He has vast hands-on design, development, and product realization experience ranging from manufacturing systems for specialized aerospace components to biomedical devices with several patents issued or under process; one of his major achievements being development of pioneering DNA Arraying System for biomedical applications culminating in sale of technology to industry for considerable fees and royalty. He is a licensed member of the Association of Professional Engineers of Ontario, Canada. He is an alumnus of University of Toronto Canada (Ph.D., 1997), IIT Madras (M.Tech., 1987), and Bangalore University (PGDM, 1984).