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Towards Green Sensing Virtual Enterprises: Interconnected Sensing Enterprises, Intelligent Assets and Smart Products in the Cyber-Physical Circular Economy

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Abstract. This paper undertakes the conceptual development of Green Sensing Virtual Enterprises (GSVEs) and their potential application environments, as goal-oriented networks that are dynamically created and composed by a short-term alliance of green enterprises with sensing capabilities, whose interactions are enabled by sensor networks and supported by computer systems, in order to answer to collaboration opportunities requiring competencies beyond those available in any single enterprise, and will evolve or dissolve once their mission is accomplished. GSVEs are seen as the organisational counterpart of intelligent assets and smart products in an emerging Dynamic Cyber-Physical Circular Economy powered by pervasive digital transformation, where the synergy of the Internet of Things (IoT) paradigm, the Sensing Enterprise (SE) capabilities and the agile and environmental-friendly nature of Green Virtual Enterprises (GVEs) will unlock the full potential of circular business opportunities.

Keywords: Green Virtual Enterprises, Sensing Enterprise, Breeding Environments, Intelligent Assets, Smart Products, Circular Economy, Internet of Things, Cyber-Physical Systems.

1. INTRODUCTION

Reflecting the necessary evolution from 'business as usual' in Circular Economy (EMF, 2016) eco-systems towards self-aware and proactive ones, where Sensing Enterprises (SEs) (FInES Cluster, 2011) and their dynamic value networks (Noran et al., 2014) interact with intelligent assets[1] (EMF, 2016) and smart products[1] (Kiritsis, 2011), this exploratory research work aims to unlock new 'circular business' opportunities (Bocken et al., 2013) that can create significant sources of sustainable value for networked Small and Medium-sized Enterprises (SMEs). This endeavour presents as a necessity in the context of exponential growth of a Digital Economy (Deloitte Digital, 2012) bringing closer than ever people, organisations and resources within (virtual) collaborative networks (Camarinha-Matos et al., 2008; 2009; 2010), and thus connecting networked manufacturers and service providers with their value offers (e.g. product-service systems (Reim et al., 2015) by means of the Internet of Things (IoT) (Ashton, 2009), Cyber-Physical Systems (CPSs) (Lee, 2008) and Future Internet Enterprise Systems (FInES) (FInES Cluster, 2009) .

Moreover, the Circular Economy (CE) is evolving towards a more Dynamic and Cyber-Physical form (DCPCE), where current circular business opportunities are being maximised by IoT, CPSs and FInES technologies and also creating new ones (e.g. digital servitization). In other words, creating new green revenue streams based on extending products' use cycle (e.g. reuse, repair and other value-added service offers) and thus creating more value from each unit of resource recovered (e.g. refurbishment, remanufacturing and recycling) enabled by the possibility of identifying, authenticating, locating, tracking and remotely interacting with intelligent assets and smart products across their entire useful life.

[1] A physical object that is able to sense, record and communicate information about itself and/or their surroundings (Kiritsis, 2011; EMF, 2016).

2. SENSING ENTERPRISES AND DYNAMIC VIRTUAL ENTERPRISES

In the context of an ever increasing Networked and Digital Economy, successful enterprises are bound to exhibit increasing pervasiveness supported by IoT, CPS and FInES technologies, which are blurring their traditional boundaries to such extent that stimuli coming from within vs. outside of the enterprise can no longer be effectively distinguished. In fact, it is not characterised only by awareness (as the term implies), but also by decentralised intelligence (Noran et al., 2014).

A SE can be described as "an enterprise that can foresee future decisions by using multi-dimensional information captured through physical and virtual objects so as to enhance its global context awareness" (FInES Cluster, 2011). SEs also feature decentralised intelligence, relevant not only to collaborative decision making, but also to purposefulness and well-being of the human side; thus, a SE can in fact be considered a *'social'* enterprise. The *'liquid'* (ubiquitous) character increasingly attributed to the SE is owing to the trend of sensors becoming a shared commodity (FInES Cluster, 2011) that allows other organisations to provide value-added services, based on observations of these sensors (Noran et al., 2014).

The typical key capabilities of the SE are awareness, perceptivity, intelligence and extroversion (Zdravković et al., 2014). *Awareness* can be internal (self-), environmental (external-) but also universal – enabling the observation of unknown or unexpected sources, whether multi-modal, multi-dimensional, discrete or continuous. *Perceptivity* is a capability of an SE to assign a *meaning* to an internal or external observation and then decide on a suitable course of action as a result of a cognitive process using *intelligence*. SE *extroversion* relates to the willingness and capability of the SE to articulate its actions and demonstrates its business motivation and/or a concern about its physical and social environment (Zdravković et al., 2014; Noran et al., 2014).

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In this context, previous research by Noran et al. (2014) has attempted to define a new type of Virtual Organisation (VO), necessary to address shortened collaboration opportunity windows and ever faster changing environments of collaborative projects. Thus, the so-called 'third generation' [2] VO-types emphasised not only the dynamic VO creation process (specific to the second generation), but also VO's *'agile'* behaviour *during* its lifecycle (*cf.* operation/evolution stages). Thus, a truly Dynamic VO (DVO) would be capable to recognise and promptly react to changes in the environment during its operation/evolution and therefore survive and adapt to change. As it became increasingly obvious that the organisational behaviour attributed to DVOs matched that of what had been described above as the *'Sensing Enterprise'*, Noran et al., 2014 advocated that the SE be the basis of the DVOs. This stance is adopted by the authors of this paper and used in this research work.

3. DYNAMIC CYBER-PHYSICAL CIRCULAR ECONOMY ENABLERS

The first source of sustainable value and enabler for a DCPCE relies on *Collaborative Networked Organisations (CNOs)* as 'virtual' (lacking a true physical manifestation *per se*) organisational forms able to grant SMEs the capability of bidding for and successfully completing projects that require capabilities beyond those of any individual member (Camarinha-Matos et al., 2009). A CNO is defined as "a network consisting of a variety of organisations that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital and goals, but that collaborate to better achieve common or compatible goals, and whose interactions are supported by computer networks" (Camarinha-Matos et al., 2008; 2009). In this paper, special attention is given to the goal-oriented CNO-type known as *Virtual Enterprise (VE),* "a short-term and dynamic coalition of enterprises that may be tailored with a breeding environment to respond to as single collaboration (business) opportunity, through integrating their core-competencies and resources required to meet or exceed the quality-, time- and cost- frames expected by the customer" (Camarinha-Matos et al., 2008; 2009). The authors focus on a particular VE-subtype known as *Green Virtual Enterprise (GVE),* "as a short-term agile alliance of green networked enterprises focused on offering, delivering and recovering green products to/from the market, under a lifecycle (circular) thinking" (Romero & Molina, 2010; 2011). Moreover, depending on its goal (delivery or recovery), a GVE can be tailored to become a *dynamic forward supply network* for delivering new green products to the market (*cf.* F-GVE, (Romero & Molina, 2014)), or a *dynamic reverse supply network* for recovering products for service provisioning, product refurbishment or safe disposal (*cf.* R-GVE, (Romero & Molina, 2013)).

[2] First Generation VOs were created from an 'open universe' of organisations, while Second Generation featured breeding environments (VBEs) to increase the preparedness of potential VO partners towards rapid VO creation and configuration; however, it must be noted that the resulting VOs were not very agile in their operation; this represented an opportunity for improvement reflected in the development of a Third Generation VOs (Noran et al., 2014).

The second source of sustainable value and enabler for a DCPCE relies on the ever increasing variety of new *'intelligent assets'* and *'smart products'* having various degrees of ability to sense, store and communicate information about themselves and/or their surroundings in order to expose (new) servitization (e.g. maintenance, repair and overhaul) and circularity (e.g. reuse, refurbishment, remanufacture and recycling) business opportunities (Kiritsis, 2011; EMF, 2016; Romero & Molina, 2013; 2014; 2015). This intelligence ('smartness') is enabled by the IoT paradigm, transforming previously passive assets and products into 'live' (active) entities capable of sharing information about their location, condition and availability; moreover, these live entities would also be capable to trigger a call for action, e.g. for service provisioning to be provided by their Original Equipment Manufacturer (OEM). As a result, intelligent assets and smart products become 'omnipresent things' that rely on an 'alert' OEM across their useful life (lifecycle), who continuously senses their status and requirements for ad-hoc service provisioning.

Based on the next generation assets and products scenario described above, the third source of sustainable value and enabler of a DCPCE identified by the authors relies on the sensing capabilities of the intelligent assets and smart products manufacturers and service providers - in other words, on the SEs (see Section 2), which are "[…] capable of anticipating future decisions by using multi-dimensional information capture through physical and virtual objects and providing added value information to enhance its global context awareness" (FInES Cluster, 2011; Noran et al., 2014). Thus, manufacturing and service provisioning enterprises will appropriately sense and capture the necessary information in real-time from intelligent assets and smart products and their environment, thus providing the enterprises belonging to that asset- or product value chain with *'sense and respond'* capabilities for a wide-ranging set of business stimuli.

In this paper, the authors employ the above-described concepts in exploring the conceptual development of *Green Sensing Virtual Enterprises (GSVEs)*, as goal-oriented cohesive and loosely coupled mini-networks that are dynamically created and are typically composed by a short-term alliance of green enterprises with sensing capabilities, whose interactions are enabled by sensor networks and supported by computer systems. GSVEs are created in order to rise to a collaboration opportunity and will dissolve once their mission is accomplished [see Figure 1].

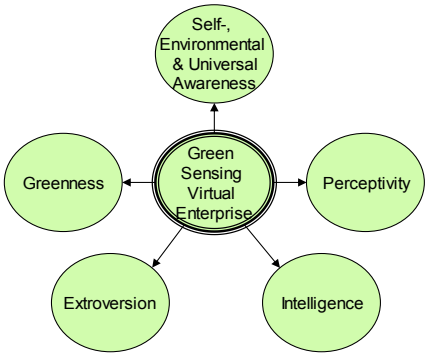

Figure 1. Green Sensing Virtual Enterprise Qualities of Being