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IFAC-PapersOnLine 48-3 (2015) 2258–2265

Green Virtual Enterprises and their Breeding Environments: Engineering their Sustainability as Systems of Systems for the Circular Economy

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Abstract: This paper aims to propose a novel 'systems of systems engineering' approach in order to achieve 'sustainability as a property' for Green Virtual Enterprises and their Breeding Environments. The research work aims to support the engineering of sustainable and viable industrial systems that can support a transition to the Circular Economy by engineering them to act in productive harmony and with

Keywords: Collaborative Networked Organisations, Green Virtual Enterprises, Breeding Environments, Industrial Ecology, Circular Ecology, Systems of Systems Engineering, Sustainability, Viable System Model.

1. INTRODUCTION

Collaborative Networked Organisations (CNOs) can be considered complex systems of systems (SoS) [Bilal et al., 2014] that emerge in many organisational forms in various domains and application environments demanding proficiencies beyond those of any individual organisation. The study of CNOs typically requires the contribution of several disciplines towards conceiving reference frameworks and methodologies for their sustainable creation, operation and evolution, possible metamorphosis and in some cases required correct dissolution [Camarinha-Matos & Afsarmanesh, 2005].

Systems of Systems Engineering (SoSE) continues to emerge as a multidisciplinary field to address complex problems in diverse domains, including sustainability with its five main areas: Environmental, Socio-Cultural, Technological, Economics, and Public Policy, as described by the Joslyn Institute for Sustainable Communities.

In this paper, authors focus on the engineering of sustainability as a property of two types of collaborative organisational systems: (a) Virtual Enterprises (VEs) seen as short-term and goal-oriented networks, tailored within a so-called 'breeding environment' for responding to a particular collaboration (business) opportunity, and (b) Virtual Enterprise Breeding Environments (VBEs) as long-term supporting networks for dynamic VEs creation [Camarinha-Matos & Afsarmanesh, 2006a; Romero & Molina; 2010b, 2011].

Note that, from a SoSE perspective, a VBE represents a system consisting of several other systems represented by the VBE members (also known as VE partners), that is a 'meta-system' for a set of systems created with its support (namely the VEs) [Romero & Molina, 2012 , Bilal et al., 2014].

The concept of sustainability takes a twofold meaning in this paper: on one hand it represents the capability to endure over time so as to continue to provide the capabilities and outcomes consisted with the assigned mission or purpose [Katina et al., 2014]; on the other hand, it is the capability to create and maintain the conditions under which industrial and natural systems can exist in productive harmony, allowing the fulfilment of economic prosperity, environmental quality and social equity for present and future generations [adapted from United States Environmental Protection Agency].

The aim of this paper is to engineer sustainability - in its dual meaning hereby defined - for VEs and their VBEs in order to support the transition of industrial systems to the so-called *Circular Economy* [Romero & Molina, 2012; Noran & Romero, 2014]; this should enable them to act in productive harmony and with restorative purposes with the *ecosphere* so that their existence can allow the creation of virtuous business value cycles and help restore natural capital.

In other words, this research explores a SoSE-based approach to engineer sustainable and viable industrial systems towards achieving an *industrial ecology,* i.e. the harmonious co-existence of industrial and natural ecosystems.

2. SoSE AND CNOs

SoSE aims towards the coordination and integration of multiple complex systems while ensuring the sustainability of the newly created system of systems as well as the continuing viability of the constituent systems [Katina et al., 2014]. However, ensuring the system of systems capability to endure in time and perform within certain economic prosperity, environmental quality and social equity levels requires a special SoSE approach. We propose an approach driven by Gagnon et al.'s [2008] *Sustainable Engineering Principles* (see Table 1), in addition to complying with the foundations set by Beer's *Viable System Model* (VSM) sub-system functions: productive, coordination, operations (including monitoring), development (including learning and transformation), and identity [Beer, 1985; Keating & Katina, 2012].

Table 1. Sustainable Engineering Principles [Gagnon et al., 2008]

Economy	• Include consumption and production goods and services into technical and natural cycles. • Support innovation to ensure continuous production quality of goods and services. • Maximise the impacts of projects on the labour market and on the quality of jobs. • Verify that the total benefits generated exceed total cost over the whole of a project's lifecycle.

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2015.06.424

Environment	• Preserve biodiversity considering the potential impacts of a project all over its lifecycle. • Keep the impacts of projects within the affected ecosystems' carrying capacity. • Limit or avoid the use of non-renewable resources during a project's lifecycle. • Spread information on the impacts to increase awareness and responsibility.
Society	• Contribute towards a safe and healthy environment along all phases of a project's lifecycle. • Help customers discriminate needs from longings so they can truly increase their wellbeing. • Ensure that projects contribute towards development of involved people and communities. • Distribute the benefits and costs resulting from a project in a fair manner.
Relations	• Enforce the precaution principle when a project may cause severe social or environmental harm. • Seek for involvement from stakeholders and other professionals to find holistic solutions. • Identify, evaluate and internalise externalities when the context makes it possible.

A CNO is a network consisting of a variety of organisations and their related support institutions that are largely autonomous, geographically distributed, and heterogeneous in term of their operating environment, culture, social capital and goals. These organisations collaborate to achieve common and compatible goals thus jointly generating new value [Camarinha-Matos & Afsarmanesh, 2005; 2006a].This definition of CNOs allows them to be engineered as systems of systems (SoS) complying with the seven essential characteristics required, namely: diversity, operational independence, geographic distribution, managerial independence, evolutionary development, emergent behaviour and connectivity - correspondingly [Maier, 1998; Stevens Institute of Technology, 2006; Bilal et al., 2014].

SoS and CNOs lifecycles pose strong similarities: (a) in the VBE case: the SoS *assembling* or *creation stage* corresponds to VBE planning, incubation and members recruitment according to core-competencies and capabilities; The SoS connectivity *(operation stage)* corresponds to the start of the VBE and its members' cooperation by sharing information, resources and responsibilities to jointly plan, implement and evaluate a program of activities for working together; SoS evolution *(evolution and metamorphosis stages)* corresponds to the VBE adapting to internal and/or external factors to maintain its sustainability; and finally, the SoS *dissolution stage* corresponds to the VBE ceasing to exist and storing or transferring its accumulated knowledge to other VBEs to enhance their sustainability [Romero et al., 2010a; Bilal et al., 2014]. (b) in the VE case: the SoS *assembling* or *creation stage* corresponds to a sub-set of VBE members starting their preparation to participate in a VE as partners, including the collaboration (business) opportunity identification and characterization, VE structure planning, VE partners' search, suggestion, negotiation and selection, and VE composition. The SoS connectivity (*operation stage)* corresponds to the VE consortia set-up and to VE partners starting to execute their join plan of activities. The SoS *evolution stage* corresponds here to the adaptation of the initial VE plan of activities by rescheduling and/or reconfiguration in order to follow as close as possible the original plan objectives; finally, the SoS *dissolution stage* corresponds to the VE ceasing to exist and sending feedback towards its parent VBE in order to enhance the network knowledge and thus future VEs sustainability [Romero et al., 2010a; Bilal et al., 2014].

3. THE THREE INTERRELATED PILLARS OF SUSTAINABILITY IN CNOs OPERATIONS

Ensuring CNO sustainability requires it to be economically prosperous, environmental friendly and socially equitable – thus, a threefold interrelated challenge. From the point of view of SoSE, these three CNO sub-challenges are the nature of the SoS (the economic industrial system - technosphere), the landscape of the SoS (the environment or natural ecosystem - ecosphere), and the variety in perspectives of the SoS (the society ecosystem - humansphere) [adapted from Katina et al., 2014].

Thus, creating a sustainable CNO SoS (in other words ensuring its specific unique green* characteristics), involves its engineering according to *Sustainable Engineering Principles* as a basic requirement. This approach can be enriched ('greened') with other sustainable principles such as *Circular Economy* (see Table 2) [Ellen MacArthur Foundation, 2012]. For example, Romero & Molina [2011] have developed a *Green Virtual Enterprise Breeding Environment (GVBE) Reference Framework* as a common architectural framework (AF) offering a clearly defined approach for conceiving sustainable, flexible and dynamic forward [2014] and reverse [2013] supply networks within a breeding environment [2010] and offering the necessary 'circular' conditions [2012] to efficiently promote the sharing, re-use and recycling of resources such as information, material, water, energy and/or infrastructure (services), based on a set of five building blocks: targets, main actors, operating principles, lifecycle support and enabling technologies.

Table 2. Circular Economy Founding Principles [Ellen MacArthur Foundation, 2012]

Circular Economy Founding Principles
• Waste is food - Eliminate/Reduce waste by cascades and reverse cycles, and cross-cycle/cross-sector collaboration. • Diversity is strength - Connections and scales are more 'resilient' in the face of internal and/or external shocks, than systems built just for efficiency. • Energy must come from renewable sources - 'Current sunshine'. • Prices must tell the truth - Reflecting the real cost of goods and services (environmental, social and economic impacts or footprints). • Systems Thinking - Understand how things influence one another within a whole.
Circular Economy Encompassing Principles
• Biomimicry - "innovation inspired by nature". • Industrial Ecology - "closed-loop processes in which waste is seen as input for another process". • Cradle to Cradle - "industrial systems must protect and enrich natural ecosystems (regenerative)". • Blue Economy (Manifesto) - "using the resources available in cascading systems, the waste of one product becomes the input to create a new cash flow".

The landscape of the CNO seen as a SoS involves all possible interactions with its surrounding and extended environments, thus including the ecosphere, humansphere, and other

*Green is used as synonym of sustainable (triple-top line [Tueth, 2010]).

technospheres (i.e. other CNOs). The engineering of GVBE as a sustainable industrial system (a green technosphere) to be integrated in a sustainable way into the natural ecosystem and the society (ecosphere + humansphere) requires sustainable interoperation with all relevant exogenous entities. In this sense, Sousa-Poza et al. [2008] depict a problem landscape that must be dealt with when engineering a sustainable SoS. A first component is *the holistic character of the problem space*; since GVEs and their breeding environments exist beyond their technosphere, decisions taken during their operations must also contemplate human/social, managerial, organisational, policy and political issues. The next component, *ambiguity,* requires GVBEs to be is regulated open, but controlled-border associations of green enterprises, featuring clear policies of member recruiting and development strategy in order to keep the breeding environment economically prosperous, environmental friendly and socially equitable according to is goals and mission. The *uncertainty* component of the problem landscape defined by Sousa-Poza et al. [2008] requires continued resolution as accumulated knowledge enhances understanding. In this sense, one of the key business processes of GVE and GVBE sustainable management must be 'inheritance management' [Karvonen et al., 2010], aiming to retrieve relevant information from past GVEs and GVBEs and create and follow a best practice to improve performance and chances of survival in the case of turbulent market conditions. The *highly contextual* feature of the problem landscape requires acknowledgement that GVEs and their breeding environments operate within the market and society, so they need to be display self-awareness and environmental awareness capabilities [Noran et al., 2014] in order to cope with the dynamic and sometimes turbulent market conditions and decide opportunely when to is time to go forward with its next lifecycle stage being an evolution or a metamorphosis. *Emergence* - i.e. GVEs and their breeding environments evolution or metamorphosis lifecycle stages imply a partial or full adaption correspondingly of existing capabilities and capacities, the creation of new ones, or even the cease of some of them to support both long- and short-term networks sustainability and therefore the reaching of their goals [Ivanov et al., 2006]. *Non-ergodicity* - i.e. GVEs and their breeding environments sustainable performance will always depend on a continuous improvement cycle driven by internal and/or external factors. *Non-monotonicity* - i.e. implying the GVBEs as long-term strategic networks, and in some cases the GVEs, will go during their lifecycle through one or more evolution stages or even metamorphosis stages to keep sustainable the network.

The variety in SoS perspectives of different stakeholders mentioned by Katina et al [2014] applies to the CNO seen as an SoS as well, because GVEs and their breeding environments may influence and be influenced (a) by customers, competitors, external institutions, potential new members/partners, etc. in the technosphere, (b) by nature events in the ecosphere, and (c) by the society in the humansphere. In this context, the ARCON reference model and modelling framework for CNOs [Camarinha-Matos & Afsarmanesh, 2006b] suggests four modelling dimensions to better characterize the interactions between a CNO and its external entities in the technosphere and humansphere: *market dimension* - covering interactions with customers, potential customers and competitors; *support dimension* - related to support services provided third party institutions; *societal dimension* - capturing all the issues related to the interactions with the society in general; and *constituency dimension* - focusing on the interactions with the universe of potential new members of the CNO. Authors suggest a fifth dimension aimed to also consider the ecosphere, tentatively named *environmental dimension* - addressing environmental-friendly interactions of the CNO with the natural ecosystem: water, air, sunlight, soil, plants, microorganisms, insects, and animals.

4. SUSTAINABILITY AS AN ENDURING CONSTRUCT FOR CNOs LIFECYCLE

The capability of a CNO seen as a SoS to endure requires significant considerations of context and deliberate planning. A possible avenue to SoS *design for sustainability* is the use of a 'meta-system'. According to Krippendorff [1986], Reza et al. [2012] and Katina et al. [2014] - a 'meta-system' is a governing structure that provides coordination and integration of systems, articulating the functions that must be performed in order to enable the sustainability of a SoS while ensuring the viability of constituent systems, thus proving mechanisms for ensuring articulated functions (and thus maintaining collaboration performance) [Westphal et al., 2007] and means for improving poorly performing mechanisms [Camarinha-Matos & Abreu, 2005]. A GVBE is an association of green enterprises and their related support institutions, adhering to a base long-term cooperation agreement, and adoption of common operating principles, interoperable infrastructures, ontologies, and mutual trust with the objective of preparing its constituent members to collaborate in potential GVEs [Romero & Molina, 2010]. Hence, a GVBE can be seen as a 'meta-system' proving a governance structure [Romero et al., 2007] for a set of systems belonging to it (i.e. the GVBE members) and for other systems created with its support (i.e. the GVEs and their partners) [Rabelo et al., 2014].

In order to engineer a sustainable CNO as 'meta-system', authors have looked into the work of Beer [1985], Keating & Katina [2012] and Katina et al. [2014] on the VSM as a cogent starting point for the engineering of sustainable GVBEs and sustainable and viable GVBE that can join and stay as part of the breeding environment to collaborate successfully but at the same remain successful as individuals.

As stated before, VSM foundation rests in five subsystems: productive, coordination, operations (including monitoring, development(including learning & transformation) and identity. These sub-systems perform a unique and vital set of functions that supports (according to Beer [1985] & Katina et al. [2014]) (a) the continued existence of the system, and (b) the system's ability to maintain desirable levels of performance in the wake of environmental flux.

Tables 3 and 4 provide a summary of the VSM functions applied to the engineering of a sustainable GVBE as an SoS based on the work of Beer [1985], Keating & Katina [2012] and Katina et al. [2014]. In particular, Table 3 focuses on the characterisation and definition of Beer's VSM sub-systems and their functions by Keating & Katina [2012], and specialises these concepts for the GVBE case.

Table 3. GVBE's VSM Sub-systems and their Functions

	VSM Function \ Primary Objectives
Sub-system 1 (Productive)	*"Produce system products and services to agree upon standards and performance levels within allocated resources (from Sub-system 3)" [Katina et al., 2014].* • A GVBE continuously develops a 'management framework', defined as a set of processes, systems and tools used by its stakeholders during its lifecycle to ensure that the breeding environment can fulfil all activities and tasks required to achieve its objectives [Afsarmanesh & Camarinha-Matos, 2005; Romero and Molina, 2009; 2010a] (from Sub-system 3). • A GVBE supports the fluid configuration of GVEs towards arisen collaboration (green business) opportunities according to its strategic, marketing and brokerage plans, conducting a bundle of activities aiming to enable alignment between the breeding environment's aspirations, the network internal core-competencies and resources and the external market, society and environmental settings [Sturm et al., 2014; Romero & Molina, 2009; 2010a]. *"Provide direct interface to the local (e.g. customer) system environment" [Katina et al., 2014].* • A GVBE provides direct interfaces to its stakeholders (internally) and interlocutors (externally) through a variety of roles assumed by different GVBE actors and systems/tools [Afsarmanesh & Camarinha-Matos, 2005; Rabelo & Gusmeroli, 2008; Romero & Molina, 2009; 2010a; 2011]. Thus, GVBE actors' roles are: (i) GVBE support providers: administrator/manager, advisor (advisory board), support institution, common tools/services and common ontology providers, public, etc. and (ii) GVE support providers: opportunity broker, GVE planner/ business integrator, and GVE coordinator. Examples of GVBE management systems and tools are the GVBE management framework, the GVE creation framework, and the GVE management framework. *"Operate autonomously to execute system work within agreed upon integration of parameters" [Katina et al., 2014].* • All autonomous and collaborative GVBE actors' operations are based on a set of identified and assigned roles with their corresponding rights and responsibilities, based on a shared and agreed governance model including principles, operational rules and bylaws [Romero et al., 2007; Rabelo et al., 2014]. *"Interface with Sub-system 2 for coordination with a larger system" [Katina et al., 2014].* • The GVBE interface with Sub-system 2 for coordination is conducted through the GVBE established actors' roles, right and responsibilities, supported by the GVBE management systems/ tools and governance model.
Sub-system 2 (Coordination)	*"Maintain coordination among productive units (Sub-system 3)" [Katina et al., 2014].* • At a breeding environment level, the GVBE administrator/manager is the actor responsible for the promotion of cooperation among the GVBE members. At the GVE level, the GVE coordinator is the actor responsible for the collaboration performance of the GVE partners [Afsarmanesh & Camarinha-Matos, 2005; Westphal et al., 2007]. *"Promote system efficiency by identifying unnecessary or redundant resources in use across productive units (Sub-system 1s)" [Katina et al., 2014].* • The GVBE administrator/manager and the GVE coordinator are responsible for filling the competency and/or resources gap in the breeding environment and the virtual enterprises respectively [Afsarmanesh & Camarinha-Matos, 2005]. Furthermore, the GVBE administrator/manager will strategize towards optimising the use of resources, closing material loops and minimising emissions; dematerialising activities, reducing and eliminating the dependence on non-renewable sources of energy [Romero & Molina, 2010; 2011; 2012].
Sub-system 2 (Coordination)	*"Identify system integration issues for system resolution" [Katina et al., 2014].* • GVBE support providers will contribute towards an advanced collaborative infrastructure enabling participants to collaborate and negotiate, systems and services to execute and adapt, knowledge and information to be exchanged and retrieved, and resources to be discovered and shared [Rabelo & Gusmeroli, 2008]. *"Identify and manage emergent conflict between Subsystem 1s" [Katina et al., 2014].* • Conflicts management within a GVBE or a GVE will follow the breeding environment and virtual enterprise policies for conflict resolution according to the governance model and the bylaws established [Romero et al., 2007; Rabelo et al., 2014].
Sub-system 3 (Operations)	*"Operational planning and control for on-going system performance" [Katina et al., 2014].* • GVBE's operations are planned and controlled by a performance management system aimed at planning workload and continuously monitoring the breeding environment as a whole and its members' performance by evolving the capacity to execute regular performance reviews and reward good performance [Camarinha-Matos & Abreu, 2005; Romero & Molina, 2009; 2010a]. Furthermore, GVEs have an execution management system aimed at monitoring the GVE and its partners' performance by tracking on-going activities [Graser et al. 2005; Ollus et al., 2007; Westphal et al., 2007; Romero & Molina, 2009]. *"Operational response to inputs from other sub-systems" [Katina et al., 2014].* • GVBE's response to any internal and/or external factor is typically supported by a decision support system (DSS) that may recommend and support entering an evolution/ metamorphosis stage to maintain its performance and goals, or extend its existence (survivability) [Romero & Molina, 2009]. GVE's response is supported by an exceptions management system that will assist in its evolution by helping in task re-scheduling, partner(s) substitution, activities and resources re-allocation and risk and budget management [Ollus et al., 2007; Hodík et al., 2007; Hodík & Stahc, 2008; Romero & Molina, 2009]. *"Interpret and implement policies and directions from Sub-system 5" [Katina et al., 2014].* • For any GVE or breeding environment lifecycle stage change, its strategic management process, led by the GVE coordinator or the GVBE administrator/manager respectively, will formulate a strategy to enable the alignment between the GVBE actors' interest, their internal core-competencies and resources, and the external market, society and environmental landscapes [Romero & Molina, 2009]. The strategy formulation process will be governed by GVBE governance rules and bylaws [Romero et al., 2007; Rabelo et al., 2014]. *"Interface with Sub-system 4 to re-design operations in response and anticipation of identified environmental shifts" [Katina et al., 2014].* • GVEs and its breeding environment will use evolution and metamorphosis to adapt to internal and/or external fluctuations in order to maintain sustainable performance. *"Negotiate resource, performance accountability, and reporting expectations for Subsystem 1s" [Katina et al., 2014].* • GVEs and their breeding environment are supported by a financial, accounting and resources management system [Romero et al., 2007], as well as by a negotiation support system [Olivera & Camarinha-Matos, 2013] that ensures the effective, efficient, and equitable use of resources in accordance with the policies and legal mandate of the GVBE governance structure [Romero et al., 2007; Rabelo et al., 2014].

Sub-systems 3* (Monitoring)	*"Monitor sub-system and system level performance" [Katina et al., 2014].* • GVBE performance management system should monitor whether progress is being made towards the desired goals and whether activities are performed efficiently and identify problems that may require additional efforts or attention. By measuring, monitoring and rating performance, a GVBE is capable to identify bottlenecks and weak links in the breeding environment and its members and act accordingly to improve the support network and its constituents' performance [Camarinha-Matos & Abreu, 2005; Romero & Molina, 2009; 2010a]. Similarly, GVEs execution management system aims to monitor the GVE and its partners' performance and provide alerts on possible inconsistencies or lack of performance in order to prevent exceptions or in case that an exception occurs, to move to a GVE evolution stage [Graser et al. 2005; Ollus et al., 2007; Westphal et al., 2007; Romero & Molina, 2009]. *"Identify and analyse deviant performance, unexpected (crises), and operational conditions and trends" [Katina et al., 2014].* • GVBE performance monitoring aims to discover potential missing competences and resources in the breeding environment by comparing its current capabilities and capacity with the future strategy, and to identify potential lack of suitable performance in the GVBE actors [Romero & Molina, 2009]. In the case of GVEs, monitoring, warning and alerting aim to proactively prevent GVE failure to deliver according to the quality-, time- and cost-frame agreed with the customer by taking timely corrective actions [Ollus et al., 2007; Romero & Molina, 2009].
Sub-system 4 (Development)	*"Foster strategic system learning, development, and transformation" [Katina et al., 2014].* • GVEs and their breeding environment employ 'inheritance management' methods (process- or documentation-based [Loss et al., 2006]) for retrieving and gathering information, knowledge and experience from different sources, in order to ensure the sustainability of the support network and future VEs [Romero & Molina, 2009; Karvone et al., 2010]. *"Maintain environmental scanning, analysis, and interpretation" [Katina et al., 2014].* • As part of their strategic and performance management processes and collaboration opportunities identification process respectively, the GVBE administrator/manager and the opportunity brokers continuously scan the environment, the GVBE and its members' capabilities, adjusting the strategic direction of the breeding environment competency requirements according to the emerging and upcoming market opportunities [Romero & Molina, 2009]. *"Maintain models of the environment, entire system, and future" [Katina et al., 2014].* • A GVBE possess a 'bag of assets' management system (a kind of content and/or knowledge management system), which serves as a (virtual) warehouse of shareable knowledge, lessons learned and other tangible and intangible assets relevant for the GVEs and breeding environment strategic management [Romero & Molina, 2009]. *"Interface with sub-systems concerning system implications stemming from environmental scanning results" [Katina et al., 2014].* • The GVBE administrator/manager and its advisory board, according to the breeding environment governance rules and bylaws [Romero et al., 2007; Rabelo et al., 2014], will take the required actions to improve the support network and GVEs' performance by means of e.g. new operational and control management approaches; recruitment, assessment, and selection of new GVBE members; re-definition and assessment of GVBE actors' roles, etc. [Romero & Molina, 2009]. *"Disseminate essential environmental intelligence information throughout the system for potential action" [Katina et al., 2014].* • The GVBE administrator/manager and management systems serve as an information centre (e.g. dashboard) for the GVBE.
Sub-system 4* (Learning & Transformation)	*"Identify, assess impact, and derive learning implications for trends, event, and patterns occurring in the system environment" [Katina et al., 2014].* • GVEs and their breeding environment learning and transformation processes are mainly guided and supported, but not limited, to the GVBE strategic, performance and inheritance management systems [Loss et al., 2006; Ollus et al., 2007; Romero & Molina, 2009; Karvonen et al., 2010]. *"Guide system transformation strategy development and implementation" [Katina et al., 2014].* • GVEs and their breeding environment transition to a evolution or metamorphosis lifecycle stage will be guided according to the established governance rules and bylaws [Romero et al., 2007; Rabelo et al., 2014], and supported by the GVBE strategic management system and GVE exceptions management system [Ollus et al., 2007; Hodík e al., 2007; Hodík & Stahc, 2008; Romero & Molina, 2009].
Sub-system 5 (Identity)	*"Maintain and propagate system identity" [Katina et al., 2014].* • GVEs and its breeding environment identity will be sustained and disseminated internally by means of actors' corresponding roles, rights and responsibilities propagation, and externally through the GVBE strategic, marketing and brokerage actions [Sturm et al., 2014; Romero & Molina, 2009; 2010a]. *"Define and clarify the system vision, purpose, mission, values and their consistent interpretation" [Katina et al., 2014].* • GVEs and their breeding environment definition of vision, purpose, mission and values will be guided according to the established governance rules and bylaws [Romero et al., 2007; Rabelo et al., 2014], and supported by the GVBE strategic and value system - management systems [Romero & Molina, 2009; 2010a]. *"Balance focus between present (Sub-system 3) and future (Subsystem 4) needs and priorities" [Katina et al., 2014].* • The GVBE administrator/manager and advisory board, and the opportunity brokers and GVEs' planners/integrators, will continuously work in the development (adaption or creation of new) appropriate management and control structures, as well as strategies, to allow the GVEs and its breeding environment to be twofold sustainable (green and viable) across their lifecycles [Afsarmanesh & Camarinha-Matos, 2005; Ollus et al., 2007; Romero & Molina, 2010a]. *"Establish system policy and strategic direction" [Katina et al., 2014].* • As stated, GVEs and their breeding environment policy and strategic direction will be determined by the GVBE administrator/ manager and advisory board, together with the opportunity brokers and possibly GVEs' planners/integrators, according to the established governance rules and bylaws [Romero et al., 2007; Rabelo et al., 2014]. *"Represent and communicate the system to external entities" [Katina et al., 2014].* • GVEs and their breeding environment are represented by all their actors, which have various representation and communication rights and responsibilities according to their roles [Afsarmanesh & Camarinha-Matos, 2005]. Moreover, a GVBE employs strategic, marketing and brokerage management systems responsible for sales and communication with external entities [Romero & Molina, 2009]. *"Process input from other Sub-systems for system implications" [Katina et al., 2014].* • Inputs from external systems can come into the GVEs and their breeding environment through, but not limited to, new GVBE members and support institutions recruiting, the GVBE strategic management process, heritage from other GVBEs, etc. [Romero & Molina, 2009].

Table 4 provides the vision of a GVBE as a 'meta-system', providing the necessary governance structure [Romero et al., 2007] for its sustainability as an SoS and viability for sets of systems that may belong to it (i.e. the GVBE members) and/or emerge from it (i.e. the GVEs) [Rabelo et al., 2014].

Table 4. GVBE's Meta-system for Governance of SoS

	Primary Objectives
Sub-system 1 (Productive)	*"Sub-system 1s (productive) represents individual complex systems that must be integrated and coordinated to formulate a system of systems, which provides an enhanced capability greater than the sum of the constituent systems" [Katina et al., 2014].* • A GVBE aims to offer its members, and to the market and society, a new collaborative and circular sustainable industrial development model characterised by economic growth, green jobs creation and environmental protection, through the creation of virtuous (viable) business value cycles and environmental restorative strategies that are beyond those achievable by a single green enterprise [Romero & Molina, 2012]. Such virtuous cycles and strategies are brought to business practice through the rapid and fluid configuration of GVEs tailored to become dynamic forward supply networks for delivering green products (virgin or used/recovered) to the market [Romero & Molina, 2014], or dynamic reverse supply networks for recovering the products sold under the GVBE brand (product stewardship) for service provisioning, product recovery or for safe disposal [Romero & Molina, 2013]. *"Constituent systems exhibit characteristics of systems of systems, operate in the system of systems problem landscape, and are subject to divergent perspectives" [Katina et al., 2014].* • When a green enterprise becomes a GVBE member, the enterprise must adhere to a cooperation agreement and to a collaborative culture compromising an orientation to openness, commitment, leadership, trust-building, self-learning, continuous training, long-term and global vision, effective communication, knowledge sharing and innovation towards a supportive and positive behaviour to enhance the capabilities of others and willingness to adapt for the benefit of all [Romero et al., 2007; Rabelo et al., 2014].
Sub-system 2 (Coordination)	*"Meta-system function 1: a meta-system function in a system of systems to maintain coordination and integration among constituent systems" [Katina et al., 2014].* • From the GVBE actors' perspective: (a) the GVBE administrator/ manager is responsible for the breeding environment actors membership and structure management and the promotion of cooperation among members and (b) the GVE planner/business integrator is responsible for selecting the appropriate set of partners for a GVE [Afsarmanesh & Camarinha-Matos, 2005; Romero & Molina, 2011]. Moreover, from a management framework perspective, the responsible systems and tools are (a) within the GVBE management framework (i.e. membership and structure management system [Sitek et al., 2007] and profiling and competency management system [Ermilova & Afsarmanesh, 2007]), (b) within the GVE creation framework (i.e. collaboration opportunity (CO) identification tool [Demšar et al., 2007], CO characterisation and GVE rough planning tool [Concha et al., 2008], partners search and selection tool [Baldo et al., 2007], and agreement/contract negotiation wizard [Olivera & Camarinha-Matos, 2013]) and (c) within the GVE management framework (i.e. GVE initiation management system [Ollus et al., 2007]).
Sub-system 3 (Operations)	*"Meta-system function 2: a meta-system function in a system of systems ensures operational planning and control of ongoing systems of systems and constituent system performance" [Katina et al., 2014].* • From the GVBE actors' perspective: (a) the GVBE administrator/ manager is responsible for the breeding environment operation and evolution and (b) the GVE coordinator is responsible for the management of the GVE during its lifecycle [Afsarmanesh & Camarinha-Matos, 2005; Romero & Molina, 2011]. From a management framework perspective, the responsible systems and tools are (a) within the GVBE management framework (i.e. strategic and marketing [Romero & Molina, 2009], financial, accounting and resources [ibid], governance [Romero et al., 2007]; bag of assets [Romero & Molina, 2009], value system [Romero et al., 2010], ontology [Afsarmanesh & Ermilova, 2007], ICT [Rabelo & Gusmeroli, 2008], trust [Msanjila & Afsarmanesh, 2007]; performance [Romero & Molina, 2009], decision support [ibid], etc.), and (b) within the GVE management framework (i.e. GVE execution and delivery [Ollus et al., 2007], GVE exceptions [Hodík et al., 2007; Hodík & Stahc, 2008] - management systems).
Sub-systems 3* (Monitoring)	*"Meta-system function 3: a meta-system function in a system of systems monitors system of systems and constituent system performance" [Katina et al., 2014].* • From the GVBE actors' perspective: (a) the GVBE administrator/ manager is the responsible for assessing the competency [Ermilova & Afsarmanesh, 2007], trust [Msanjila & Afsarmanesh, 2007], and performance levels [Romero et al., 2010] of a breeding environmental actor; and (b) the GVE coordinator for the case of the GVE partners [Afsarmanesh & Camarinha-Matos, 2005; Romero et al., 2009; Verdecho et al., 2010; Romero & Molina, 2011]. Moreover, from a management framework perspective, the responsible systems and tools are (a) within the GVBE management framework (i.e. membership and structure [Sitek et al., 2007], and profiling and competency [Ermilova & Afsarmanesh, 2007]), (b) within the GVE creation framework (i.e. partners search and selection tool [Baldo et al., 2007]) and (c) within the GVE management framework (i.e. GVE executing and delivery [Ollus et al., 2007], and exceptions [Hodík et al., 2007; Hodík & Stahc, 2008] - management systems).
Sub-system 4 (Development)	*"Meta-system function 4: a meta-system function in a system of systems that fosters learning, development, and transformation" [Katina et al., 2014].* • From the GVBE actors' perspective, the GVBE administrator/ manager and the GVE coordinators are those responsible for fostering learning, development, and transformation through strategic, performance, inheritance and bag of assets management [Afsarmanesh & Camarinha-Matos, 2005; Karvonen et al., 2010; Romero & Molina, 2011]. From a management framework perspective, the responsible systems and tools are (a) within the GVBE management framework (i.e. strategic and marketing, performance, and bag of assets - management systems [Romero & Molina, 2009]) and (b) within the GVE management framework (i.e. GVE inheritance management system [Karvonen et al., 2010]).

Sub-system 4* (Learning & Transformation)	*"Meta-system function 5: a meta-system function in a system of systems that identifies, assesses impacts, and derives learning implications for trends, events, and patterns occurring in the systems environment" [Katina et al., 2014].* • From the GVBE actors' perspective: the GVBE administrator/ manager and the advisory board, the opportunity brokers, and the GVE planners/business integrators are those responsible for strategizing corrective actions or future directions for the breeding environment. Moreover, from a management framework perspective, the responsible systems and tools are: (a) within the GVBE management framework (i.e. strategic and marketing, performance, and decision support - management systems [Romero & Molina, 2009]), and (b) within the GVE management framework (i.e. GVE inheritance management system [Karvonen et al., 2010]).
Sub-system 5 (Identity)	*"Meta-system function 6: a meta-system function that maintains and propagates systems of systems identity" [Katina et al., 2014].* • From the GVBE actors' perspective, all internal and external communications and information exchange will take place according to the GVBE governance structure [Romero et al., 2007; Rabelo et al., 2014]. From a management framework perspective, the responsible systems and tools are (a) within GVBE management framework (i.e. membership and structure [Sitek et al., 2007], strategic and marketing, governance, and bag of assets - management systems [Romero & Molina, 2009]) and (b) within the GVE management framework (i.e. GVE inheritance management system [Karvonen et al., 2010]).

5. CONCLUSIONS

Engineering sustainability in a SoS requires maintaining the right balance between the effective and efficient operations of its constituent systems and can be assisted by observing the meta-system and SoS problem landscape paradigms as described. Developing sustainable (green and viable) SoS requires enabling their co-existence with other systems (the ecosphere, humansphere and other technospheres), as well as maintaining and evolving desired characteristics such as competitive advantage to support their enhanced mission and performance.

This research work leverages on existing reference models and frameworks (e.g. [Romero & Molina, 2011]), and SoSE rules for building SoS complying with the Gagnon et al.'s Sustainable Engineering [Gagnon et al., 2008] and Beer's Viable System Model [Beer, 1985] principles.

The degree to which these principles are effectively performed and coupled with suitable mechanisms determines the efficacy of SoS sustainability and the viability of the constituent systems [Katina et al., 2014].

Finally, three key elements are required to establish sustainable GVEs and their breeding environments operations [Beckett, 2004]: (a) a governance model that defines clear actors' roles, operational rules, bylaws and principles [Romero et al., 2007; Rabelo et al., 2014], (b) brokerage services that deliver perceived sustainable value (economic prosperity, environmental quality and social equity), and (c) balancing the complementary and similar features that enhance the resilience of the SoS [Camarinha-Matos, 2014].

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