



## Review Article

# Designing sustainable product-service systems: A generic process model for the early stages

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## ABSTRACT

The design of Product-Service Systems (PSS) in manufacturing companies has been widely researched over the past three decades, with contributions from various backgrounds. However, the multidisciplinary field led to the development of disparate approaches for PSS design, which furthermore deficiently include sustainability considerations. Such discord hinders PSS uptake in industry due to the unclarity of which process to use and crucial matters to consider. This paper aims to propose a generic process model to describe the early stage of the PSS design, which is the most influential phase for the success of the PSS offering throughout its life cycle, concerning the three dimensions of sustainability. The proposed generic process model addresses early-stage PSS design in three phases and considers seven clusters of entities through five activities. To achieve this aim, existing approaches for PSS design were identified through a systematic literature review, yielding a comprehensive overview of existing approaches distilled with respect to their content, the actions they propose and the sustainability principles they discuss. The systematic review was then followed by in-depth content analysis using widely adopted methodologies in design research and manufacturing companies for process decomposition and consequently synthesis, resulting in the proposed systematic generic process model for the early-stage design of sustainable PSS. The proposed process model was further examined concerning its use implications, limitations, and potential implementation steps.

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## 1. Introduction

The motivation to design Product-Service Systems (PSS) has been changing since the concept's inception often accredited to Goedkoop et al. (1999). Early research into the field was driven by the aim of achieving the environmental sustainability potential of PSS (Mont, 2004). Henceforth, numerous authors from other fields (e.g. engineering design, business management, information systems) have joined the discourse (Boehm and Thomas, 2013; Pezzotta et al., 2015), and a multitude of approaches for PSS design have been developed (Cavaliere and Pezzotta, 2012; Qu et al., 2016; Vasantha et al., 2012), yet with inconsistent terminology and objectives (Peruzzini and Wiesner, 2020). Although the developed approaches address many important gaps, studies of companies attempting to utilise them show disappointing success rates, with respect to being able to deliver both profitable (Neely, 2008) and environmentally sustainable (Bech et al., 2019) offerings to the market.

PSS is currently enjoying revived attention in up-to-date literature, mostly due to advances in digital technology and a focus on circular economy (CE) (Pirola et al., 2020) as a means to achieving sustainability (Kjaer et al., 2018). It is expected that the intense period of development of PSS approaches will culminate in the coming years with an accentuated emphasis on consolidation and integration of existing approaches (McAlloone and Pigosso, 2017; Pigosso et al., 2015), which is the main focus of this research. Such PSS business models have also been recognised by the European Commission as one of the key instruments to consider toward the 2030 sustainability targets (European Commission, 2015, 2019).

Already a decade ago, Boehm and Thomas (2013) underlined that the major task of future contributions in the PSS field should include a reach across disciplinary boundaries (e.g. engineering design and business management) involved in PSS design. Despite this assertion, the literature is sparse on the integration of PSS development activities (Peruzzini and Wiesner, 2020), particularly in a collaborative way at the early stage of design (Pezzotta et al., 2018). There is currently a lack of approaches to support the design of PSS, especially when conceptualising and carrying out the early PSS design stages (Barravecchia et al., 2020); some suggestions are to be found within the literature, but are spread and remain largely at a qualitative level (Sakao and Neramballi, 2020). The process models reported in the literature are dissimilar in the activities they propose (Marques et al., 2016), and sustainability is tackled sporadically and superficially (Moro et al., 2022; Qu et al., 2016).

No comprehensive or generic framework has been found for early-stage PSS design that unifies existing proposals in a synergetic way and no early-stage PSS design process model can be treated as a de facto standard in industry, which leaves theoretical contributions untested and uncomplete (Chiu et al., 2018; Clayton et al., 2012; Guillon et al., 2021; Sakao and Neramballi, 2020). This research, therefore, sets out to identify patterns in the existing approaches to the early stage of sustainable PSS design and propose a generic process model, as merely coalescing existing methods and process models is unlikely to bring novelty on its own (Song and Sakao, 2017).

The following sections elaborate on the state-of-the-art literature (Section 2), describe the methodology (Section 3), present the phases and entities that constitute the generic process model along with the necessary sustainability considerations (Section 4), discuss the key findings and insights (Section 5), and conclude with clearly outlined contributions (Section 6).

## 2. Background

### 2.1. PSS design

PSS is a life cycle-oriented marketable blend of tangible and intangible offerings, supported by the infrastructure and the actor-network, designed to deliver more value than traditional transactional offerings (Mont, 2004). PSS design is the interdisciplinary process of ideating, selecting and developing a PSS concept into an offering (Vasantha et al., 2012), and is an integral part of service-related business development (Bech et al., 2019).

PSS design implies a particularly wide area of intervention when compared to traditional product design (Morelli, 2006), as more knowledge domains need to be involved and more complexity is introduced (Nemoto et al., 2015; Shimomura et al., 2015). This complexity can largely be attributed to the heterogeneity of design elements and their variants to be concurrently considered (Barravecchia et al., 2020). In addition, the differentiation between the PSS design task and the business development activity in a company becomes increasingly blurred, as PSS presents itself in different patterns than traditional product development or service development (Maussang et al., 2009).

Despite its many-year development in different fields, only meagre research has been conducted on how to actually support the PSS design process in practice (Haber and Fargnoli, 2017). Incipient considerations of PSS design support propose a four-stage process (Clayton et al., 2012), often comparable to the stages devised in traditional product development reference models, such as Pahl and Beitz (2004): planning and clarifying; conceptual design; embodiment design; and detailed design. The intricate activities within each stage of the PSS design process are not well clarified and diverge greatly in the literature (Trevisan and Brissaud, 2016), thus making it difficult to set the boundaries on the early-stage PSS design (Rosa et al., 2017). Contributing authors from mixed backgrounds propose approaches with disparate phases and activities in the design process (Marques et al., 2016). The approaches identified predominantly omit to detail the early design process beyond the description of high-level phases (Haber and Fargnoli, 2017) and they have different starting and ending points (Clayton et al., 2012). As a result, PSS design processes continue to be vague in the literature.

### 2.2. The lack of support for the early-stage PSS design

As established in the design science literature, the early-stage PSS design encompasses planning and conceptualisation stages (Rosa et al., 2021) that result in an assessable PSS concept (Welp and Sadek, 2008).

The early stage of PSS design ending with conceptualisation plays a key role in PSS design (Alonso-Rasgado et al., 2004; Peruzzini and Wiesner, 2020), as it works as a compass in implementation and defines the value to be provided to beneficiaries (Kimita et al., 2009). The early design stage leads to the definition of new PSS concepts that can satisfy stakeholders' needs and identify the required resources to do so (Rondini et al., 2016). Since the existing definitions of the PSS concept as the output of the early design phases have discrepancies (see e.g. Sutanto et al. (2015) or Song and Sakao (2017)), in this research, the PSS concept is defined as: "an actionable (implementable) and assessable (screenable) design proposal describing the total solution including the system's composition, its functionalities and business model that fulfil the requirements of the involved actor-network".

In contrast to embodiment and detailed design, the early-stage PSS design deals primarily with what should be offered, rather than how to deliver the offering, and therefore focuses on the definition of the product functions, the service elements, the infrastructure and the network of players, as well as their interaction (Barravecchia et al., 2020). In early-stage PSS design, the system that is to be designed ought to be analysed within a wider beneficiary's system than in pure product design, meaning that PSS design involves many more actors and systems managed by those actors (Trevisan and Brissaud, 2016).

Important characteristics of early-stage PSS design include the structuring of innovative thinking for concept generation (Yang and Xing, 2013) and the high volatility and unavailability of early-design information (Sousa-Zomer and Miguel, 2017), where relevant information may also get ignored (Rosa et al., 2021). The applicability of quantitative methods (Bertoni and Bertoni, 2020) and the ability to use data-intensive techniques is limited (Rondini et al., 2020). Furthermore, the early-stage PSS design is often limited to functional analysis in which stakeholders' involvement and product-service compatibility are overlooked (Haber and Fargnoli, 2017; Maussang et al., 2009).

There is a greater opportunity in early-stage PSS design to use systematic approaches for avoiding sub-optimal decisions concerning cost and risk (Bertoni et al., 2019) and to prevent resource allocation on design concepts with doubtful odds of success (Tran and Park, 2016). Lindahl et al. (2006) point out that it is crucial to learn as much as possible about the evolving PSS early in the development process because the market success of PSS can be attributed to decisions taken in the early stages, as that is when the changes are the least expensive (Schmidt et al., 2015).

Despite its criticalities and opportunities, early-stage PSS design in manufacturing companies is predominantly characterised by intuitive approaches (Aurich et al., 2006) supported by many different models (Rondini et al., 2016), as existing approaches are difficult to implement in an industrial context (Andrianakaja et al., 2016). The result is often an inefficient and erroneous early-stage design process where PSS designers largely rely on their experience (Yang and Xing, 2013) and abilities rather than systematic approaches (Kim and Yoon, 2012).

Existing models for early-stage PSS design advise disparate phases (Marques et al., 2016) and are largely focused just on a part of the complete early-stage PSS design, e.g. a business model (Adrodegari et al., 2017) or PSS requirements (Sousa-Zomer and Miguel, 2017). Therefore, the individual methods seldomly resolve the problem of PSS concept generation on their own (Kim and Yoon, 2012; Sousa-Zomer and Miguel, 2017). Moreover, the majority of the process models have a high level of abstraction of phases which are separated by instances of evaluation and decision-making (gates). Thus, process models remain incomplete and undetailed (Haber and Fargnoli, 2017), and in most cases, inefficient (Sakao et al., 2020).

Predefined generic PSS design process models have the potential to support companies in systematically capitalising on positive effects and avoiding negative effects of PSS (Aurich et al., 2006; Vasantha et al., 2015). Early-stage PSS design is considered to be best facilitated through a systematic approach (Yang and Xing, 2013) that can be adjustable for individual practitioner purposes (Becker et al., 2010).

### 2.3. Sustainability in early-stage PSS design

PSS could be powerful enablers of sustainability, both economically, environmentally and socially (Aurich et al., 2006; Sarancic et al., 2022). PSS has the potential to accomplish a positive sustainability impact in the triple-bottom-line (TBL) (Elkington, 1998; Isil and Hernke, 2017; Purvis et al., 2019), through e.g. stable and predictable revenue over time, prolonged product useful life and greater customer acceptance (Chiu et al., 2018). However, PSS offerings are not intrinsically sustainable (de Jesus Pacheco et al., 2022) and their sustainability performance remains case-dependent (Sutanto et al., 2015).

Even though PSS has been discussed as a direct means toward achieving sustainability (Kjaer et al., 2018; Koide et al., 2022), PSS offerings are not by default more sustainable than the individual product (Bech et al., 2019; Tukker, 2015) and some PSS offerings may even produce unintended side effects, commonly referred to as rebound effects (Metic and Pigosso, 2022), in any of the three dimensions of sustainability (Doualle et al., 2015).

Sustainability considerations should be made throughout the PSS design process, starting in the early stages, which determine most of its sustainability impact (Pigosso and McAlloone, 2015; Sousa-Zomer and Miguel, 2017) and where the greatest opportunities for more sustainable solutions lay (Maxwell and Van der Vorst, 2003). However, this is also the stage where the least is known about PSS and where manufacturing companies face challenges (Kolling et al., 2022). Therefore, support for companies is needed from a process perspective in sustainable PSS design (Pieroni et al., 2017).

Current models for early-stage PSS design do not fully support the creation of the TBL sustainable PSS offerings, and few approaches found in the past literature incorporate sustainability principles in the early-stage PSS design (Moro et al., 2022) while a need for such approaches has been long vocalised in literature (Ny et al., 2013). Early customer involvement is also pivotal to connecting the value network between various stakeholders and embedding sustainability visions in early-stage PSS design, thus tackling social sustainability (Chen, 2018).

A habitual misbelief prevails in the PSS design literature that following a PSS design process instead of a mere product design process will automatically yield a more sustainable offering, but that is not necessarily the case (Tukker, 2015). Although many approaches claim to produce more sustainable offerings, few explicitly incorporate sustainability principles and even fewer in the early-stage PSS design (Sousa-Zomer and Miguel, 2017). When the sustainability principles are incorporated into the design process, a more sustainable outcome offering can be expected (Pigosso et al., 2013).

The instructions on how and when to pragmatically embody these considerations in early-stage PSS design process remain vague in the extant approaches. Sustainability must be considered throughout the process and in many constituent entities and activities, not only in the evaluation, as mostly proposed in the literature (Qu et al., 2016). Even those sparse methods that propose sustainability considerations in the early-stage PSS design in the literature tend to be ajar in between each other and are most often not suited for the early stages of design with so many unknowns (Doualle et al., 2020). Therefore, despite numerous proposals in the literature, a comprehensive process for sustainability-integrated early-stage PSS design remains unclear.

### 3. Methodology

The research commenced with the identification of the research gap, i.e., the need for a generic process model for the early-stage design of sustainable PSS, ahead of conducting a systematic literature review (SLR) (de Almeida Biolchini et al., 2007). To set the direction of SLR, dominant literature reviews on PSS design (Boehm and Thomas, 2013; Cavalieri and Pezzotta, 2012; Clayton et al., 2012; Pirola et al., 2020; Qu et al., 2016; Sakao and Neramballi, 2020; Tukker, 2015; Vasantha et al.,

2012) were examined to get an overview of the most recurrent approaches and adopted methods.

Based on the overall objective, four research questions (RQ) to be answered through SLR were formulated:

- RQ1 – What are the main phases and activities conducted in the existing early-stage PSS design approaches?
- RQ2 – What constituent entities of early-stage PSS design do the existing design approaches consider?
- RQ3 – How to unify the existing perspectives in a generic, yet readily applicable process model for early-stage PSS design?
- RQ4 – What are the sustainability considerations in the existing early-stage PSS design approaches and how to incorporate them into the proposed generic process model?

The research questions naturally progress from process to content inquiry of the existing approaches. The first two questions do not focus on approaches that explicitly include sustainability considerations, to widen the search. The third question synthesises the answers to the first two questions in a new process model, while the fourth question inquires deeper into the sustainability aspects of early-stage PSS design. To answer the research questions, an SLR was conducted following a protocol devised by [de Almeida Biolchini et al. \(2007\)](#), which comprises three activities: data collection, analysis and reporting.

### 3.1. Data collection

Data collection consisted of a search and selection procedure ([Fig. 1](#)) of available publications in Scopus. After conducting the initial search in both Scopus and Web of Science (WoS) databases, Scopus was selected

due to the fact that results yielded from the latter in a great measure represented a subset of the results from Scopus, therefore a more comprehensive database was selected.

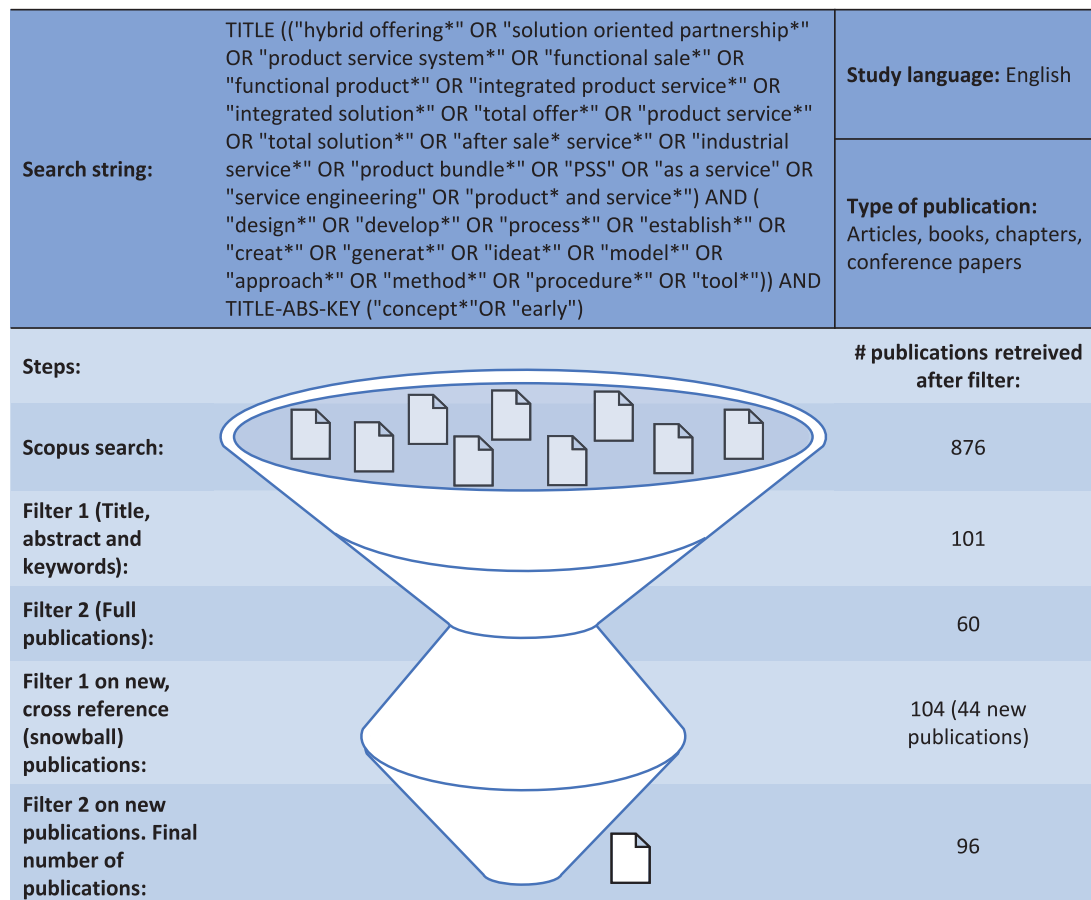
The final search was carried out in August 2022 and resulted in 876 unique publications. The elicited publications were subject to two filters: (1) the title, abstract and keywords; and (2) a full read of selected publications to determine whether they satisfied the inclusion criteria:

1. The study must report at least one method, tool, or approach to support early-stage PSS design or an integrated PSS development process described in sufficient detail.
2. The study must relate to manufacturing companies.

Snowballing ([Wohlin, 2014](#)) was performed to identify publications falling outside of the database search (through cross-reference), thus also capturing the publications from the WoS, which resulted in the identification of 44 additional publications. The same filters and criteria were applied to select the publications obtained initially from the Scopus database and to the publications identified through snowballing. The snowballing procedure continues until the saturation point, i.e., the exhaustion of available publications that satisfy the above criteria.

In total, 96 studies were selected (full list in the Supplementary material).

Although the search string focused on early-stage PSS design and conceptual design, which are often used interchangeably in literature ([Welp and Sadek, 2008](#)), the final set of publications reached through snowballing includes many of the approaches with a much wider scope than early-stage PSS design (e.g. [Van Halen et al., 2005](#); [Tukker and Tischner, 2006](#)). Those renowned publications in a great measure



**Fig. 1.** Systematic literature review search parameters, process, and results.



contributed to the completeness and boundary setting of the early-stage PSS design process.

### 3.2. Data analysis

From the set of 96 selected publications, 96 approaches were identified as potentially relevant for early-stage PSS design. To answer the first two research questions, content analysis was conducted, employing coding and thematic organisation (Dresch et al., 2015) of constituent entities, activities and tools, which enabled comparisons across approaches despite disparate nomenclatures. The categorisation was achieved by observing patterns that emerged during the data analysis and related activities. Here, constituent entities were grouped through emergent pattern identification (Yin, 2003). The constituent entities imply objects of design or consideration which can be grouped in a cluster, the activities are the necessary actions to conduct during the design process, and the tools are design supports that can facilitate the design process to yield optimal returns (Rondini et al., 2016).

The theoretical framework selected to aid the analysis of the data was IDEF0 (ISO 31320-1, 2012). IDEF0 is a functional modelling language that uses Inputs, Controls, Outputs, and Mechanisms (ICOM) for process decomposition and mapping which enabled the achievement of a baseline for the comparison across different elicited approaches. IDEF0 supports a methodical approach to PSS design (Morelli, 2006), ensuring success in both product, service and PSS design (Trevisan and Brissaud, 2016), and wide adoption in industrial companies. Furthermore, IDEF0 aligns well with the Theory of Technical Systems (TTS) (Hubka and Eder, 1988), an adjacent theory in the design of technical systems useful as a rational basis for examining engineering design processes. The approaches elicited from the literature were deconstructed using IDEF0 and used as inputs to contrive a generic process model for early-stage PSS design.

Following the analysis of all the selected approaches, eight of them are selected for an in-depth analysis, based on four criteria (focus on sustainability, validated industrial applicability, level of detail, and the number of citations), to serve as a mainframe for the development of the generic process model. Those criteria were selected because the paper aims to ensure the widespread applicability of the generic process model in industry, the inclusion of sustainability considerations, as well as sufficient detail of the model.

### 3.3. Data synthesis

To answer the third research question, a unified and generic process model for early-stage PSS design has been proposed following the structure of the Rational Unified Process (RUP) (Kruchten, 2000). The RUP devises a structured time-based evolution of a process in which various constituent entities need to be considered at different moments, thus enabling effort prioritisation over time.

The findings from the analysed approaches were synthesised to yield a generic process model and a recommendation of the sequence of phases, activities, and constituent entities to be considered during early-stage PSS design (Section 4.3). The synthesised process model was initially verified by a panel of academic experts and industry specialists from a manufacturing company, through a series of meetings and feedback sessions.

The proposed process model served as a canvas for answering the fourth research question, as it was developed in such a way that enables the mapping of sustainability considerations throughout early-stage PSS design.

## 4. Results

The identified approaches are significantly dissimilar in three ways, relating to: (i) the granularity level of phases' descriptions and the number of phases/activities; (ii) the number and types of constituent entities

of early-stage PSS design and (iii) the level of inclusion of sustainability considerations. The further sections elaborate on these three points, while more detailed descriptive findings can be found in the Supplementary material.

### 4.1. Phases and activities of the existing approaches to early-stage PSS design

Of the 96 approaches, only eight have a comprehensive consideration of the early-stage PSS design, i.e. they consider all the cluster entities defined in Section 4.2, the TBL and life cycle thinking (see Supplementary material for more detail). Those eight approaches were examined more closely (Fig. 2) and compared with respect to four criteria to select the mainframe of the generic process model for early-stage PSS design:

- C1. Focus on sustainability
- C2. Validated industrial applicability
- C3. Level of detail in terms of all the entities considered
- C4. Number of citations in the literature

Most of the approaches have a wider focus than just the early-stage PSS design. Although employing quite different nomenclature and the scope of the phases, the eight approaches have many similarities regarding the overall process and considerations they propose. The similarities manifest in the cadence of activities of most approaches, but also in the contents of the phases (e.g. most approaches agree on the contents of the ideation phase, whether they call it idea development, idea generation and evaluation or identification of products and services).

Subject to the four criteria, the approaches proposed by Van Halen et al. (2005), and Tukker and Tischner (2006) proved the most relevant. Due to their resemblance in terms of proposed phases (Fig. 2), a similar mainframe focused on early-stage PSS design consisting of three phases was adopted, namely: (i) strategic planning, (ii) exploring opportunities and (iii) PSS concept development which include activities in the eight analysed approaches until the red line indicated in Fig. 2. The name of the first phase has not been adopted from any of the existing approaches but was instead adapted to more closely reflect the contents of that phase which are deemed wider than just analysis or an introduction.

The researchers devise different process models i.e. phases and activities to design PSS concepts and their constituent entities, however, they use similar workflows to transform inputs into outputs no matter the constituent entity. Even though the existing early-stage PSS design literature does not follow any set process, the sequence of actions or nomenclature concerning activities needed to design the constituent entities is similar. The analysis of the existing approaches revealed the pattern of the most common activities, usually described with one of the following five action words or their synonyms in chronological order: identification, analysis, definition, selection and refinement. Those five activities in a workflow are, therefore, needed to design any of the constituent elements (e.g. identification, analysis, definition, selection, and refinement of requirements), and are one of the key elements to devise a generic process model (Section 4.3).

### 4.2. Entities to consider in early-stage PSS design

The following sub-sections elaborate on the constituent entities of early-stage PSS design, elicited from the 96 relevant approaches and classified into seven overarching clusters (Table 1): business model, the network of actors, requirements, functions, offerings, structure, and the plan for implementation, as elicited from the literature.

#### 4.2.1. Business model

A business model describes how a company creates, captures and delivers value (Pieroni et al., 2019a). The core dimension that drives Business Model Innovation (BMI) is the value proposition, which indicates the value that the provider may offer to all the actors in the network through PSS (Fernandes et al., 2020). Most of the value of a

Sources	Phases						C1	C2	C3	C4
(Van Halen et al., 2005)	(1) strategic analysis	(2) exploring opportunities	(3) idea develop.	(4) PSS development	(5) implemen. preparation		++	++	++	+
(Aurich et al., 2006)	(1) demands identif.	(2) feasibility analysis	(3) concept development	(4) service modelling	(5) realization planning	(6) service testing	+	++	+	++
(Tukker and Tischner, 2006)	(1) preparation and introduction	(2) analysing PSS opportunities	(3) PSS idea generation	(4) PSS design	(5) make implement. plan		++	++	++	++
(Müller et al., 2009)	(1) collation of prerequisites		(2) stepwise, iterative modelling and integrated deduction of means for further development		(3) deployment of results		-	+	+	-
(Vasantha et al., 2011)	(1) customer needs	(2) existing customer capabilities	(3) identify products and services		(5) specify responsibilities	(8) evaluation and contract finalization	-	+	+	-
	(6) identify bus. models	(4) identify manufact. and supplier capabilities	(7) identify additional capab. required							
(Vezzoli et al., 2014)	(1) incubation	(2) socio-technical experimentations		(3) niche development and scaling up			++	+	++	+
(Pieroni et al., 2019a)	(1) prepare	(2) Sense	(3) Seize		(4) transform		++	+	+	+
(Peruzzini and Wiesner, 2020)			(1) idea generation	(4) PSS design	(5) PSS test	(6) PSS implement.	+	-	+	-
		(3) requirements	(2) idea evaluation			(7) PSS launch				

Early-stage PSS design ←

**Fig. 2.** The phases in the eight most comprehensive approaches. The phases are colour-coded according to their contents, in comparison to the approach in the first row. The approaches are rated according to the level to which they satisfy the four criteria. The end of the early-stage PSS design is indicated with the red line. Legend: (++) satisfy to great extent, (+) satisfy to some extent, (–) poorly satisfy.

PSS concept is defined in the early stages (Kimura et al., 2009; Sakao and Neramballi, 2020), but it is difficult to anticipate the actual value for the involved actors at this early point (Panarotto et al., 2017), as value

perceptions vary and are individual to each recipient (Song and Sakao, 2017) and can only be understood when the offering is in use (Meier et al., 2011).

Many alternative value propositions might look promising, therefore, to gain a deeper insight into their potential, the generation of several alternative use scenarios can be conducted to develop the idea further in a particular context (Maussang et al., 2009). Scenario generation is one of the critical steps in early-stage PSS design (Yang and Xing, 2013) as it is a source of a variety of receiver behaviours to be studied when delivering the service and where the receiver state parameters (RSPs) are changed (Sakao and Shimomura, 2007). The use of scenarios implies devising a temporal organisation of actions that actors take in a particular context (Trevisan and Brissaud, 2016), enabling designers to investigate the way actors might behave (Maussang et al., 2009).

The business model cluster and its constituent entities, elaborated using IDEF0 throughout the three phases of early-stage PSS design, can be seen in Fig. 3.

#### 4.2.2. Network of actors

It is considered that the value beneficiaries seek can be most effectively delivered by the homogenisation of offerings of a network of cooperating companies (Pawar et al., 2009), which must be done early in the PSS design (Mougaard et al., 2012). Stakeholders' involvement is often disregarded in the existing approaches (Haber and Fargnoli, 2017), and PSS designers plead for approaches that incorporate stakeholder preferences in PSS design (Vasantha et al., 2012). The importance of considering the structure of relationships within the network stems from the possibility to identify opportunities for new constellations of revenue, information and resources required for innovating and sustaining a PSS offering (Mougaard et al., 2012), as well as its optimal operation (Alonso-Rasgado et al., 2004).

The network of actors includes several categories of external participants involved in early-stage PSS design (such as customers, partners,

**Table 1**  
Constituent entities of early-stage PSS design clustered, as elicited from the literature.

Clusters	Cluster descriptions	Constituent entities
Business model	The way a company creates, captures, and delivers value.	Value proposition, use scenarios
Network of actors	All the external stakeholders' relationships and interactions in an ecosystem which engages in PSS provision.	Customers, partners, suppliers, and competitors
Requirements	The minimum acceptable standards that the PSS concept should satisfy over its life cycle and according to the TBL.	Demand, wishes, needs, specifications, engineering characteristics, contradictions
Functions	A set of qualities with a particular purpose associated with the PSS offering that can be decomposed and accredited to different elements of the concept.	Functional unit (FU), sub-functions, performance, satisfaction unit
Offerings	Product and service components, their modules together with architectures, interfaces, and the related processes.	Product (the main tangible artefact) and service (intangible artefact), PSS delivery process
Structure	All the support resources and their internal organisation that are enabling the delivery of the value of the offering.	Infrastructure (periphery, support systems), organisational structure, capabilities, resources, logistics
Plan for implementation	A roadmap with a timeline of required activities to realise the conceived PSS concept with assigned responsibilities.	Deployment plans, responsibilities, roles, project key performance indicators

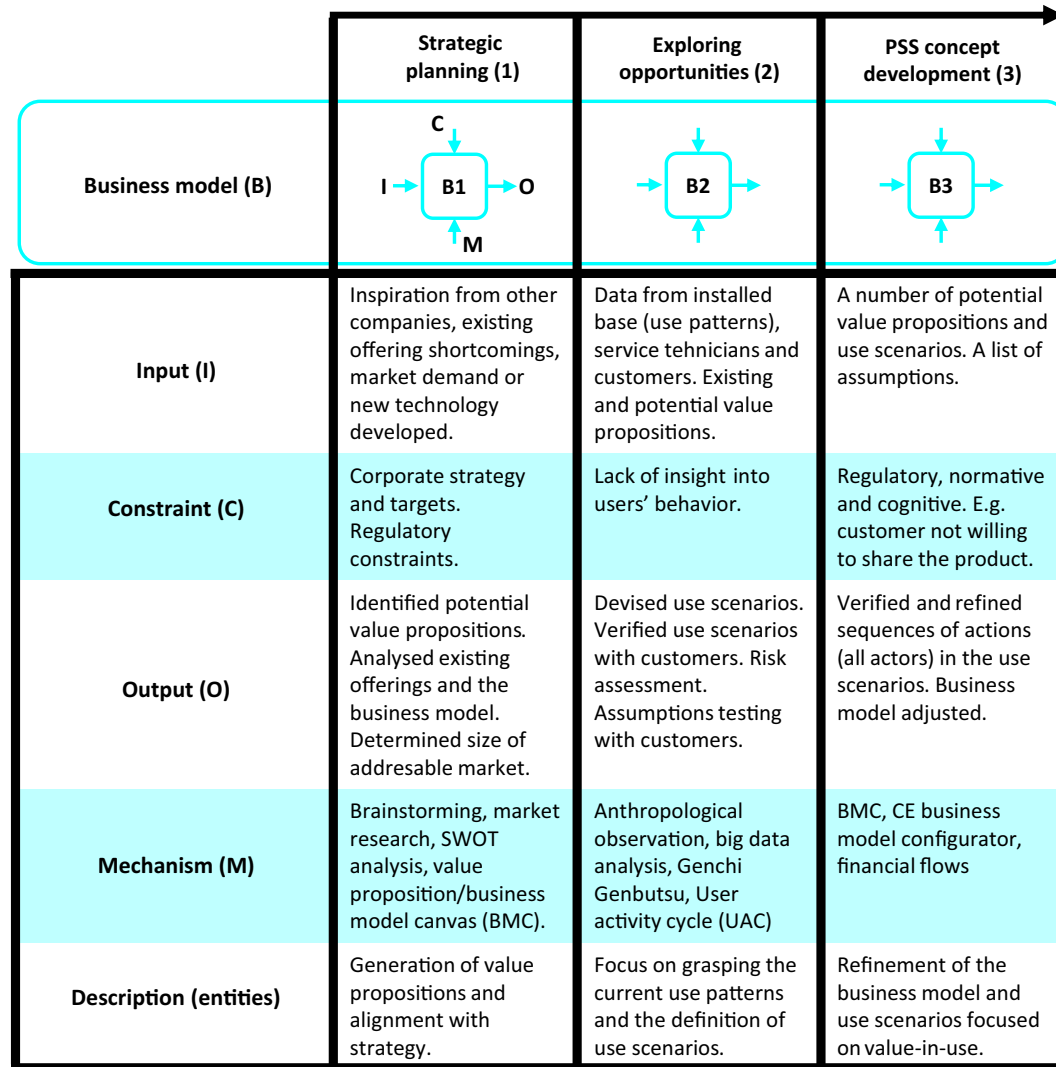


Fig. 3. Business model cluster mapped into ICOM notation in the three phases of early-stage PSS design.

suppliers and competitors) (Sakao and Neramballi, 2020). This cluster focuses primarily on external relationships in a wider sense than customarily considered in BMI. The internal organisational structure is considered a part of the structure cluster (Section 4.2.6), as it is where the PSS-providing company has the direct responsibility to design it while the external network can only be influenced. Hence, the network of actors could be defined as a conglomeration of all upstream and downstream offering value chain actors involved in the co-creation of the PSS offering.

Customers and users are not solely the targeted consumers, but they represent an invaluable source of insights to be actively utilised in PSS design (prosumers) (Mougaard et al., 2012), and so do the partners (Maussang et al., 2009).

Alongside the community directly interfacing with the PSS offering, there is a wide range of both governmental and non-governmental potential partners essential to be mapped and aligned (Rosa et al., 2016) including, but not limited to the authorities, legal bodies, and conservation institutions (Lindahl et al., 2006), and service contractors, energy providers, financing institutions and consultants (Trevisan and Brissaud, 2016), respectively.

Suppliers of the physical materials and sub-parts which will build up the tangible parts of the PSS offering as well as the supporting infrastructure (Section 4.2.6) have to be carefully contemplated due to: the risk of extended commitments necessary for cost-effective component

delivery (Alonso-Rasgado et al., 2004), environmental impact and transparency in their supply chain, and timely and reliable delivery (Maxwell and Van der Vorst, 2003).

Competitors are most often a source of learning and uncovering unserved market spaces for a PSS designer (Rondini et al., 2016). In some cases, however, competing companies can partner up for the benefit of both in terms of shared costs of transport or operations, or in certain market segments where they do not compete directly (Neugebauer et al., 2013).

Therefore, the significance of the various actors in the network is manifold in terms of their roles and potential contributions to the creation of value, and thoughtful selection and planning of actors' interventions in the early-stage PSS design can have a profound impact on the success of PSS offerings.

The network of actors' cluster and its constituent entities, elaborated using IDEF0 throughout the three phases of early-stage PSS design, can be seen in Fig. 4.

#### 4.2.3. Stakeholders requirements

Customer needs in a great measure determine the PSS configuration (Pawar et al., 2009) and their elicitation and formalisation in the early stages are often considered an input for the conceptual design of PSS (Song and Sakao, 2017). However, due to the vagueness of PSS innovation, the requirements cannot be fully defined before the PSS concept

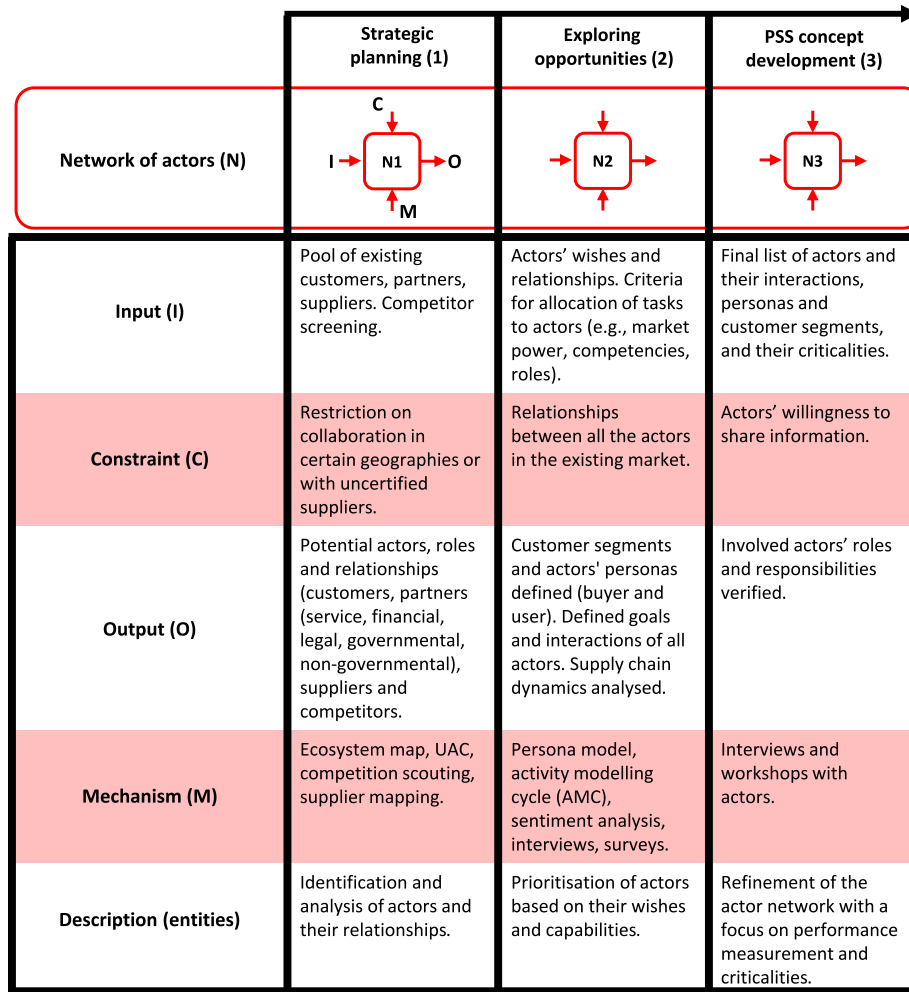


Fig. 4. Network of actors cluster mapped into ICOM notation in the three phases of early-stage PSS design.

development phase begins, therefore understanding customer needs remains a major challenge as many needs are tacit and change over time (Rexfelt and Hiort Af Ornäs, 2009). For that reason, continuous requirement elicitation starting from an early phase from not only customers but all involved stakeholders has been heralded as one of the pivotal factors in successful early-stage PSS design (Sousa-Zomer and Miguel, 2017). Apart from a larger number of requirement demanders, the requirement definition for PSS implies a broad inquiry into more than just technical requirements to support early-stage decision-making (Bertoni et al., 2013). Rather, it requires consideration of the whole system-in-use, i.e. the use context to identify “the need behind the need” (Tukker and Tischner, 2006), which comes in contrast to the focus on just product and service requirements where scant information can be obtained (Hussain et al., 2012). Therefore, an integrated approach to need elicitation and requirement consolidation is required (Sutanto et al., 2015), one that is focused on the requested function-in-context (see Section 4.2.4).

Within this cluster of entities, another critical activity is the translation of the requirements into measurable engineering characteristics or specifications and their prioritisation (Geng et al., 2010; Sousa-Zomer and Miguel, 2017). These specifications ultimately determine the performance measurements and the constraints of the offering in the sense of their operating boundaries (constraints) and forbidden design features for whatever reason (Maussang et al., 2009). The definition of the specifications almost inevitably causes a conflict between them (Kim and Yoon, 2012), where the improvement of one parameter

causes the deterioration of the other (Yang and Xing, 2013). The resolvment of these contradictions shows great promise in early-stage PSS design (Song and Sakao, 2017).

The requirements cluster and its constituent entities, elaborated using IDEF0 throughout the three phases of early-stage PSS design, can be seen in Fig. 5.

#### 4.2.4. Life cycle functionality

The consideration of functionality during the complete life cycle can enhance the overall performance of PSS (Song and Sakao, 2017). This consideration should happen concurrently with requirement elicitation, by stating the requirements on the requested function, rather than in the product- or service-focused domain (Lindahl et al., 2006). Zhang (2013) extends this line of thinking by referring to PSS performance consisting of the function and its quality, which is the expression of function level and its availability over time. Sousa-Zomer and Miguel (2017) argue that even the definition of engineering characteristics must be considered in the functional domain because the final functionality satisfying the customer should be the inception of business development (Rexfelt and Hiort Af Ornäs, 2009).

Functional analysis (Kim and Yoon, 2012), i.e. the elaboration of the PSS function into its sub-functions is seen as a step in a gradual process toward the generation of a comprehensive PSS concept (Haber and Fargnoli, 2017). This consideration is not limited only to the function that the main offering delivers (Kimita et al., 2009), but also the set of functions that enable its delivery, executed either by the supporting



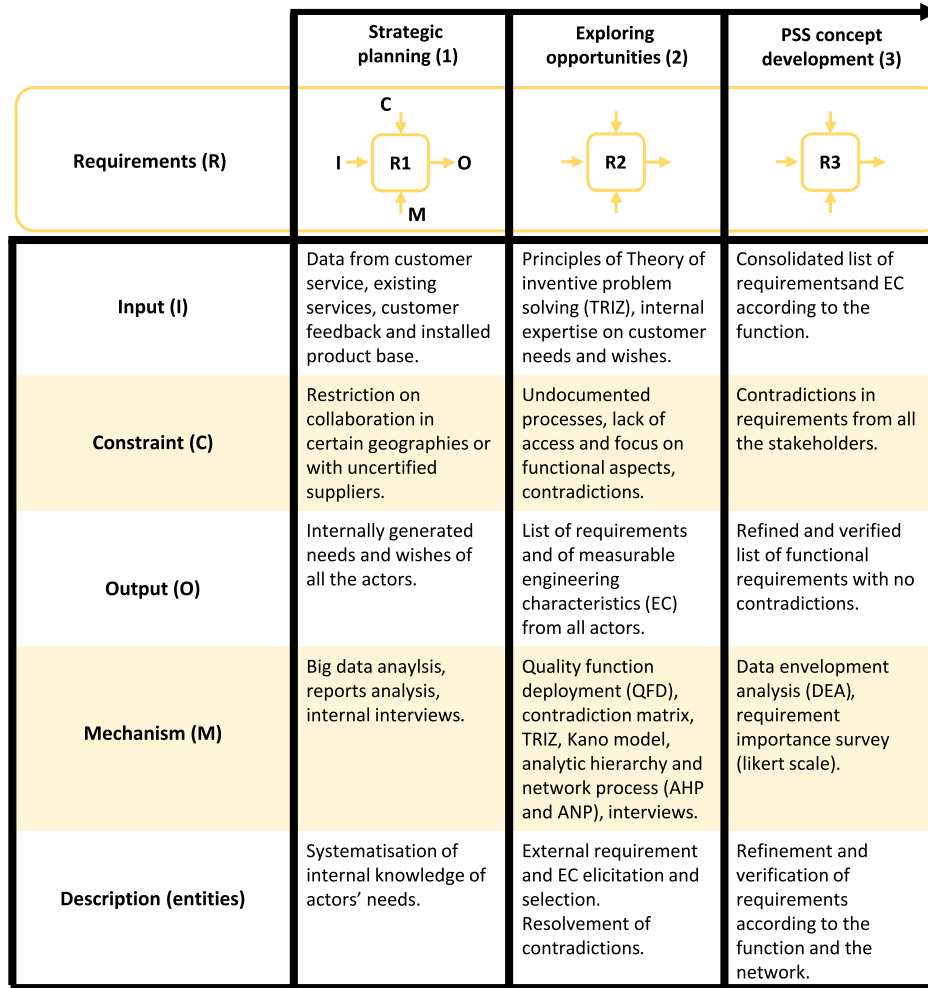


Fig. 5. Requirements cluster mapped into ICOM notation in the three phases of early-stage PSS design.

infrastructure or the involved stakeholders (Alonso-Rasgado et al., 2004). To analyse such functions, Maussang et al. (2009) introduced interaction and adaptation functions that reflect the function provided by the product to the external environment and reactions or adaptations of the external environment, respectively.

All those functions ought to have a common goal of providing functionality that positively influences sustainability and forms a value proposition for the involved stakeholders (Rexfelt and Hiort Af Ornäs, 2009). Therefore, a functional unit (ISO 14040, 2006) definition is necessary for the early-stage PSS design, both to increase the range of potential design solutions that can fulfil the set function and to allow designers to compare the total environmental impacts of alternative PSS concepts per unit of functionality (Sakao and Neramballi, 2020).

The functions cluster and its constituent entities, elaborated using IDEF0 throughout the three phases of early-stage PSS design, can be seen in Fig. 6.

#### 4.2.5. Offerings

The offering within the early-stage PSS design implies the main product and service components to realise the value proposition together with their interrelationships (tangible or intangible) (Alonso-Rasgado et al., 2004). It has a synonymous meaning with the PSS architecture (Shimomura et al., 2015) and it implies a much deeper inquiry into the composition of the offering than in a high-level consideration advocated in BMI.

Product and service elements and the modules they create together are the main components (i.e. the content) of the PSS offering as perceived by the customer, where the product can be observed as a vessel for service elements to be delivered (Aurich et al., 2006). A PSS module can be described as an integrated product and service with strong interdependencies among each other and different interfaces to the rest of the PSS concept (Song and Sakao, 2017).

The PSS content has to be distinguished from a channel or the delivery process to realise it (Sakao and Shimomura, 2007). As proposed by Ramaswamy (1996), the delivery process comprises the design of the service encounter environment, provider behaviour and customer-provider interaction. Since the delivery and the consumption of services is concurrent (Uno actu principle) (Becker et al., 2010), the delivery process should be meticulously planned to be able to deliver offering effectively and efficiently to beneficiaries (Alonso-Rasgado et al., 2004). The customer processes should be studied in-depth and should be reassessed with respect to what the customers think is their job in servicing the equipment (Hussain et al., 2012).

The offerings cluster and its constituent entities, elaborated using IDEF0 throughout the three phases of early-stage PSS design, can be seen in Fig. 7.

#### 4.2.6. Structure

The PSS structure can be broken down into several building blocks: infrastructure, organisational structure, capabilities and the required resources.

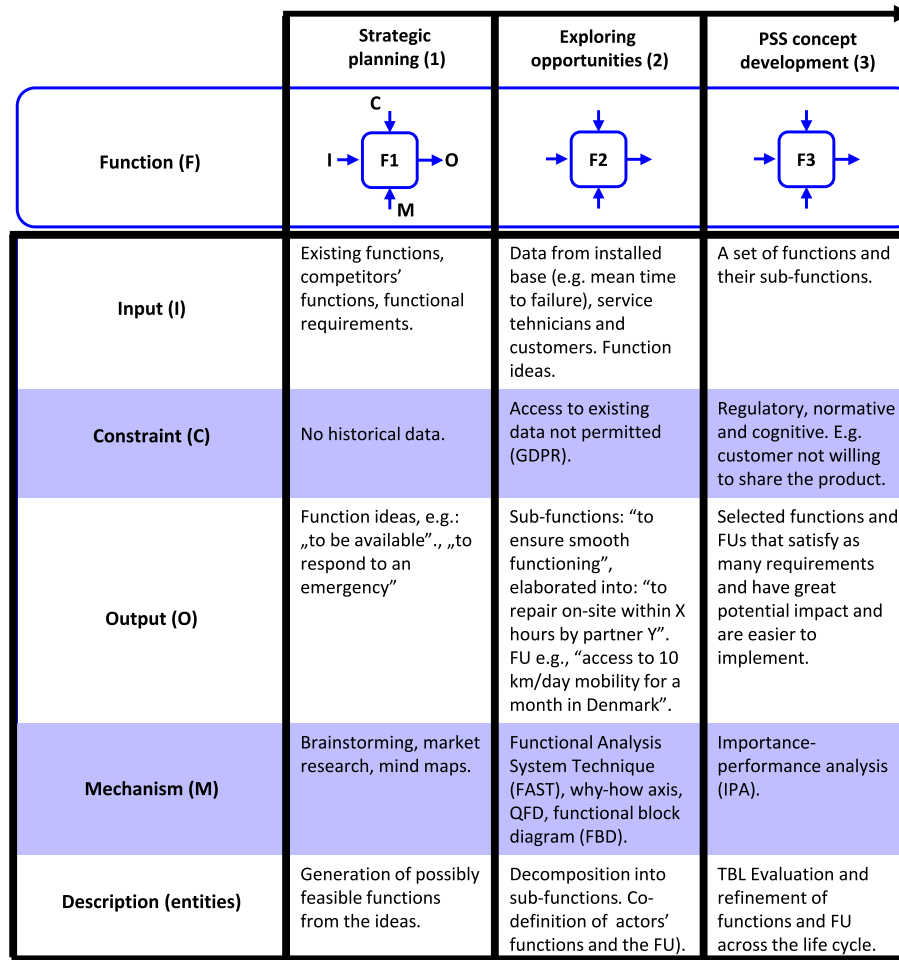


Fig. 6. Function cluster mapped into ICOM notation in the three phases of early-stage PSS design.

The infrastructure or periphery includes all the support systems that enable the delivery of value of product and service modules through supporting equipment, software, facilities, tools, logistics, etc. (Shimomura et al., 2015). This support system operates in backstage and is not directly visible to the customer, but it directly increases the value of providers' assets and differentiates them from the competition (Müller et al., 2009). Consequently, the existing infrastructure may have a notable influence on the selection of the ultimate business model.

The organisational structure describes the organisation of the internal provider's stakeholders' interactions for fulfilling the beneficiary's needs (Trevisan and Brissaud, 2016). The definition of the organisational structure is important to generate cohesion and optimal operation of PSS and enable the successful servitisation of a company system (Morelli, 2006). Capabilities influence the PSS organisation, and if missing, they should be acquired externally, either through collaboration or the acquisition of external partners (Pawar et al., 2009).

The required resource implies all resources needed to realise any of the aforementioned constituent entities, and apart from the material resources, this category includes time, cost, human resources, the information needed from the installed base and current processes (Adrodegari et al., 2017).

The structure cluster and its constituent entities, elaborated using IDEF0 throughout the three phases of early-stage PSS design, can be seen in Fig. 8.

#### 4.2.7. Plan for implementation

The final cluster entity to be conceived in early-stage PSS design is the implementation or realisation plan based on all previously

described constituent entities of a PSS concept. The implementation plan is a roadmap with a timeline of required activities to realise the early-stage PSS design with assigned responsibilities of the actors in the network, including the contract drafting (Müller et al., 2009), the deployment plans (e.g. guidelines, checklists to be used by service staff) and staff training according to the necessary capabilities (Aurich et al., 2006). Existing PSS design approaches are short of such operational implementation planning guidelines in the industrial context (Andriankaja et al., 2016), but it is essential to account and plan for critical assumptions testing and validation of critical elements of the offering delivery to the market (Mauassang et al., 2009). PSS is known for its implementation difficulty (Geng et al., 2010), therefore a systemised implementation and operation plan with the application of project management techniques to replace formerly intuitive activities is judged to be of substantial assistance (Aurich et al., 2006). The implementation plan is not often considered a part of early-stage PSS design, but within the complex PSS design domain, it is advisable to conceptually define such a plan in the early phases of PSS design because it can cause meaningful impacts in later stages (Rosa et al., 2021).

The plan for implementation cluster and its constituent entities, elaborated using IDEF0 throughout the three phases of early-stage PSS design, can be seen in Fig. 9.

#### 4.3. A generic process model for early-stage PSS design

This section intends to target the third research question by devising a generic process model for early-stage PSS design (Fig. 10), which was built utilising the main findings and patterns observed concerning the

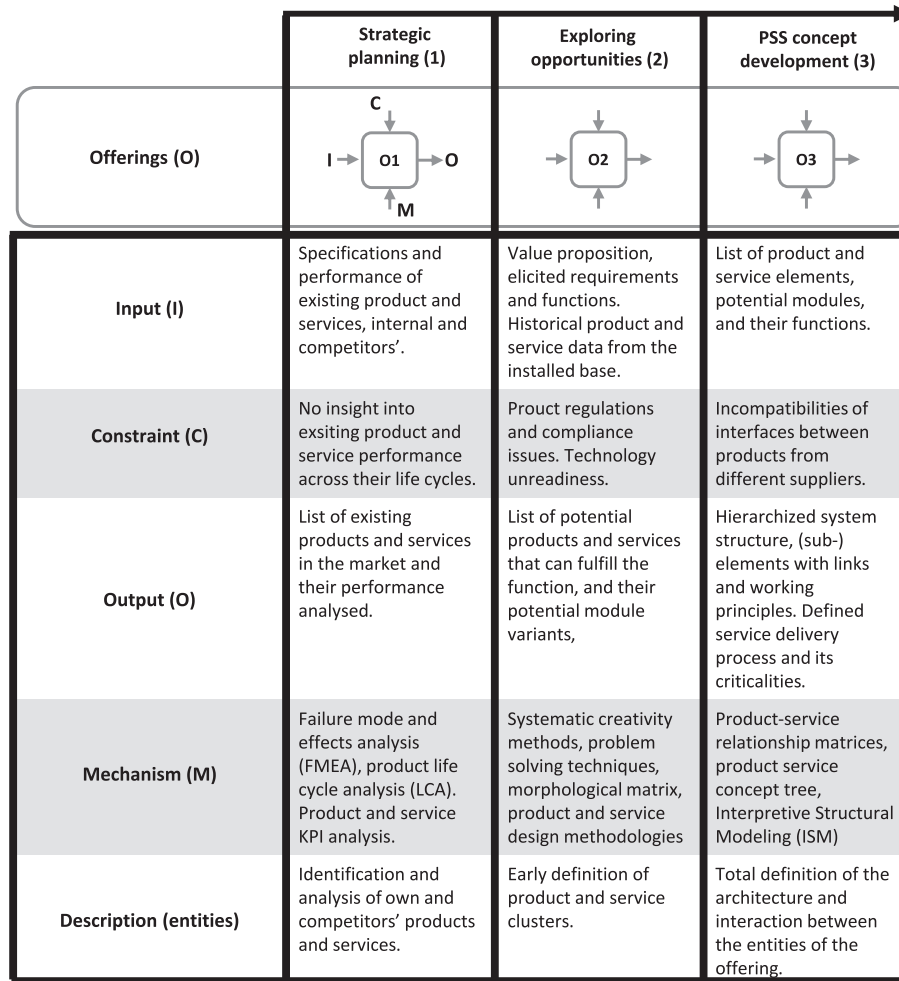


Fig. 7. Offerings cluster mapped into ICOM notation in the three phases of early-stage PSS design.

workflows of activities, phases (Section 4.1) and gates (Fig. 11) to design them in the horizontal axis and the constituent clusters of entities (Section 4.2) in the vertical axis.

The three phases of the generic process model are separated by the decision-making gates demarked with lowercase letters a-d at each gate. Exclusively of the first gate, a decision based on the outputs of the previous phase must be made concerning the continuation of the PSS design project into the next phase. The notion of a highly formalised development process, where phases are delimited with gates (i.e. phase reviews) is regarded as having a positive influence on the efficiency of the development process (Holahan et al., 2014).

The process is envisioned to be used for different types of PSS innovations, namely radical, really new and incremental (Garcia and Calantone, 2002). The three innovation types have different scopes, and they focus on either a completely new PSS concept which embodies new technology and new market infrastructure (radical), a new concept in which technology or the market is changed (really new), or an incremental change of the existing PSS offering (e.g. optimising the service delivery process), respectively (Fig. 10). Therefore, the innovation type is a determinant factor for practitioners to select the starting point in the process model.

As this is a generic process model, which must be instantiated to company-specific context by the practitioners, no strict flow of actions is devised within each of the three phases, other than the chronological execution of the five activities (I. identification, II. analysis, III. definition, IV. selection, and V. refinement). Even though some focus should be given to all seven cluster entities in every phase of the generic process

model (as indicated by trapezoids in Fig. 10), there are certain clusters of particular focus in every phase. Described phase by phase and separated by the gates, typical activities in the process model are described in Fig. 11.

Although the clusters are represented as independent modules, they are mutually interconnected and inseparable (Rosa et al., 2021) from other clusters within each phase of early-stage PSS design, as described in Fig. 11. The idea of the design process modularisation was introduced in the early days of PSS design (Aurich et al., 2006), where a process module is defined as a logically differentiable building block of a process, characterised by inputs and outputs with standard interfaces. Other authors successfully applied modular design thinking to trace the process of design through independent modules (Song and Sakao, 2017), where some process modules must be connected, and others conducted by complementing the corresponding inputs and outputs (Aurich et al., 2006), e.g. the outputs of the network cluster in phase one are inputs both to the phase two of the network and the business model clusters (see Supplementary material for more details about IDEF0 in the PSS development arena).

Therefore, the proposed generic process model contributes both to devising a meta-model, i.e. the structure of the process model itself (Becker et al., 2010), and the reference model which provides the necessary domain knowledge to be utilised in early-stage PSS design.

#### 4.4. Sustainability considerations in early-stage PSS design

The generic process model for early-stage PSS design presented in Fig. 10 will not necessarily yield a sustainable offering unless such

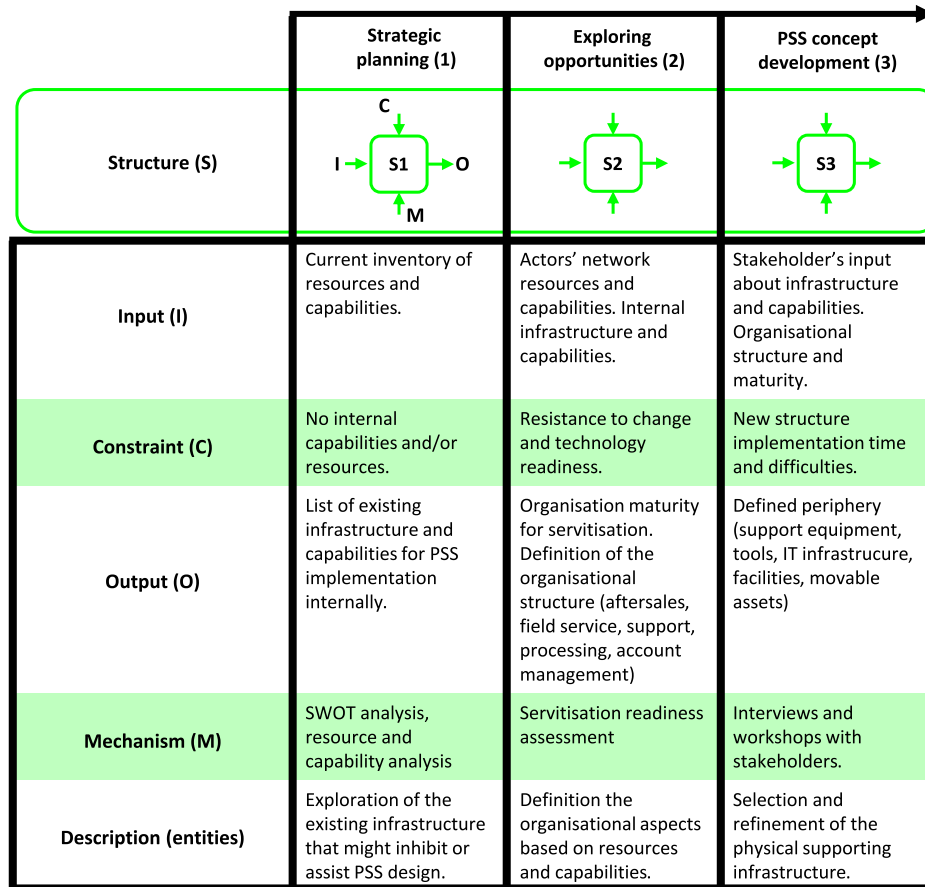


Fig. 8. Structure cluster mapped into ICOM notation in the three phases of early-stage PSS design.

considerations are thoughtfully made during the process. Many of the existing process models do not allow for such considerations and their exclusive attachment to any of the phases or constituent entities but are instead considered as vague transversal deliberations, therefore, it is uncertain what considerations to make and at what time. The generic process model proposed here is made fitting to sustainability considerations as it contains all the entities and a temporal perspective crucial for such considerations. In Fig. 12, the RQ4 is explicitly answered, as the relevant windows of opportunities to make different types of sustainability and circularity considerations and apply particular practices are indicated. Those considerations and practices can be applied throughout the three phases and are related to the seven clusters of entities. As in Fig. 10, no strict flow of considerations is devised due to the generic nature of the process model, which has to be instantiated to specific case applications and adapted to the context in which it will be used.

After receiving scarce initial attention from research, especially including the total TBL perspective (Kristensen and Remmen, 2019), PSS business model design has been recognised as much needed from a management perspective (Adrodegari et al., 2017) under the auspices of sustainable and circular BMI (Pieroni et al., 2019b) that represent a more strategic innovation at a business model level where the long-term potential must be balanced with short-term decisions (Panarotto et al., 2017). The key to circular or sustainable PSS BMI is to include the sustainability considerations and circular strategies (e.g. design for durability and take-back) into the value proposition design (Kristensen and Remmen, 2019) which will down the line guide the physical offering design. The design of a value proposition is a complex and unpredictable task in early-stage PSS design (Panarotto et al., 2017), but is a crucial piece as it is where the PSS offering's relationship to

sustainability is primarily defined, while the offering (Section 4.2.5) is merely a way to deliver the value proposition. Therefore, sustainability and circularity have to be instilled in the value proposition and identified throughout the entire PSS life cycle (Nemoto et al., 2015).

The interconnection and collaboration of different stakeholders in an ecosystem are seen as crucial to innovation and change and one of the keys to designing TBL sustainable PSS (Chen, 2018). PSS can have a tremendous impact on the communities it operates in (Maxwell and Van der Vorst, 2003), and its success is in a great measure reliant on transparent long-term partnerships and customer loyalty (Moro et al., 2022).

Requirements have to be identified, analysed, and defined through all the life cycle phases (Song and Sakao, 2017) and all three dimensions of sustainability (Sousa-Zomer and Miguel, 2017). It is important to judge the value of the concept through the lens of both life cycle and sustainability dimensions (Nemoto et al., 2015) and also consider sustainability as a source of value (Kristensen and Remmen, 2019). To seize more value from sustainability endeavours, even a larger context behind the involved parties' needs (e.g. social issues such as labour right) should be recognised (Chen, 2018).

PSS's contribution to sustainability is bound to its functionality, as PSS has the potential to help decouple the volume of produced products from profitability by managing it based on functional value rather than materials content, hence reducing the impact on the environment (Wu et al., 2021). The functional requirements can cause many trade-offs between environmental and traditional considerations such as quality and cost (Pigosso and McAloone, 2016), and it is, therefore, pivotal to set the priority TBL performance indicators already in the strategic planning phase.

Environmental sustainability in traditional product development is a large body of knowledge, which has repeatedly proven the importance



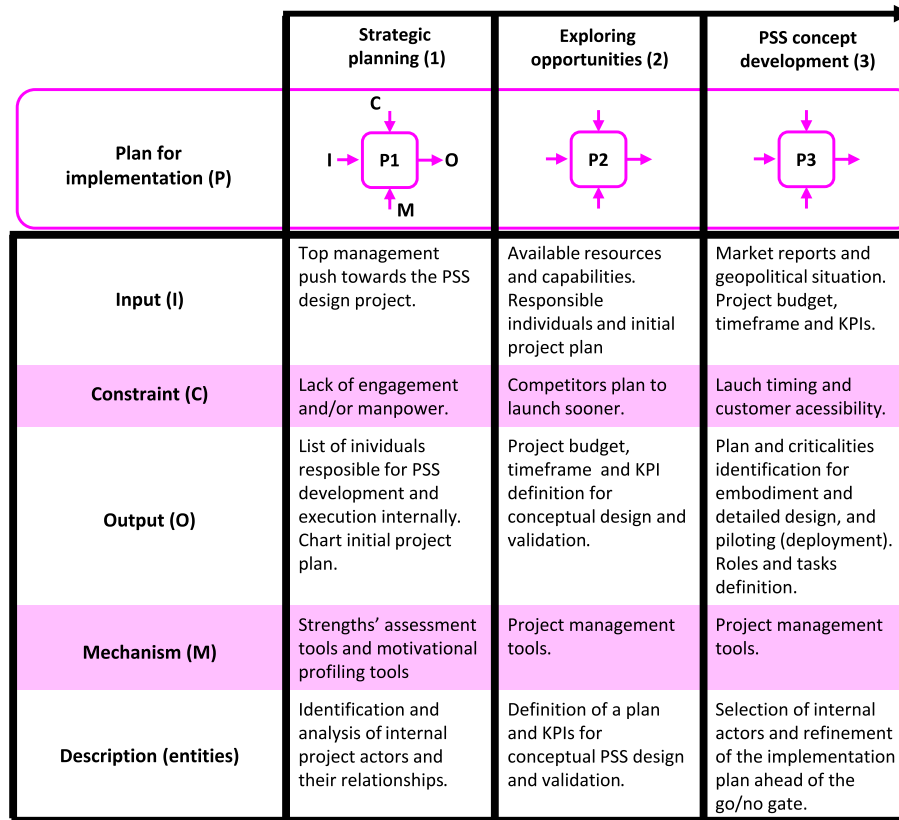


Fig. 9. Plan for implementation cluster mapped into ICOM notation in the three phases of early-stage PSS design.

of ecodesign and DfX (e.g. design for longevity) tools and principles to design more sustainable products throughout their life cycles (Pigosso et al., 2013).

The bulk of infrastructure consists of auxiliary products which can be designed using the same principles as with the main artefact. The design of a structure requires a long-term commitment and there is a real possibility that the lack of consideration of infrastructure, the provider's internal performance and coordination of capabilities and resources can erode a company's economic sustainability in the long run (Pezzotta et al., 2018). Even though the PSS has been stressed as one of the most effective instruments to enhance resource efficiency (Tukker, 2015), the identification of resource redundancies has not been addressed properly in the literature (Vasanthan et al., 2015), and the allocation of available resources should be considered with great care (Shimomura et al., 2015).

#### 4.5. Initial actions to implement the generic process model in a case study

The proposed generic process model serves as a reference starting point for manufacturers to tailor their designated process for early-stage PSS design, both in terms of the structure of the model itself and the necessary domain knowledge. It is considered that most practitioners (designers) will need to tackle the majority of entities and activities proposed in the generic process model to design a PSS from scratch, but some activities might be redundant depending on the stage of the company in their journey to adopt PSS. However, every practitioner should instantiate the generic process model to fit industry- and company-specific contexts, select the entities to address, and assign the exact flow of actions according to the company's readiness.

The instantiation process for the practitioners at a case manufacturing company with an established product design process, but not a PSS

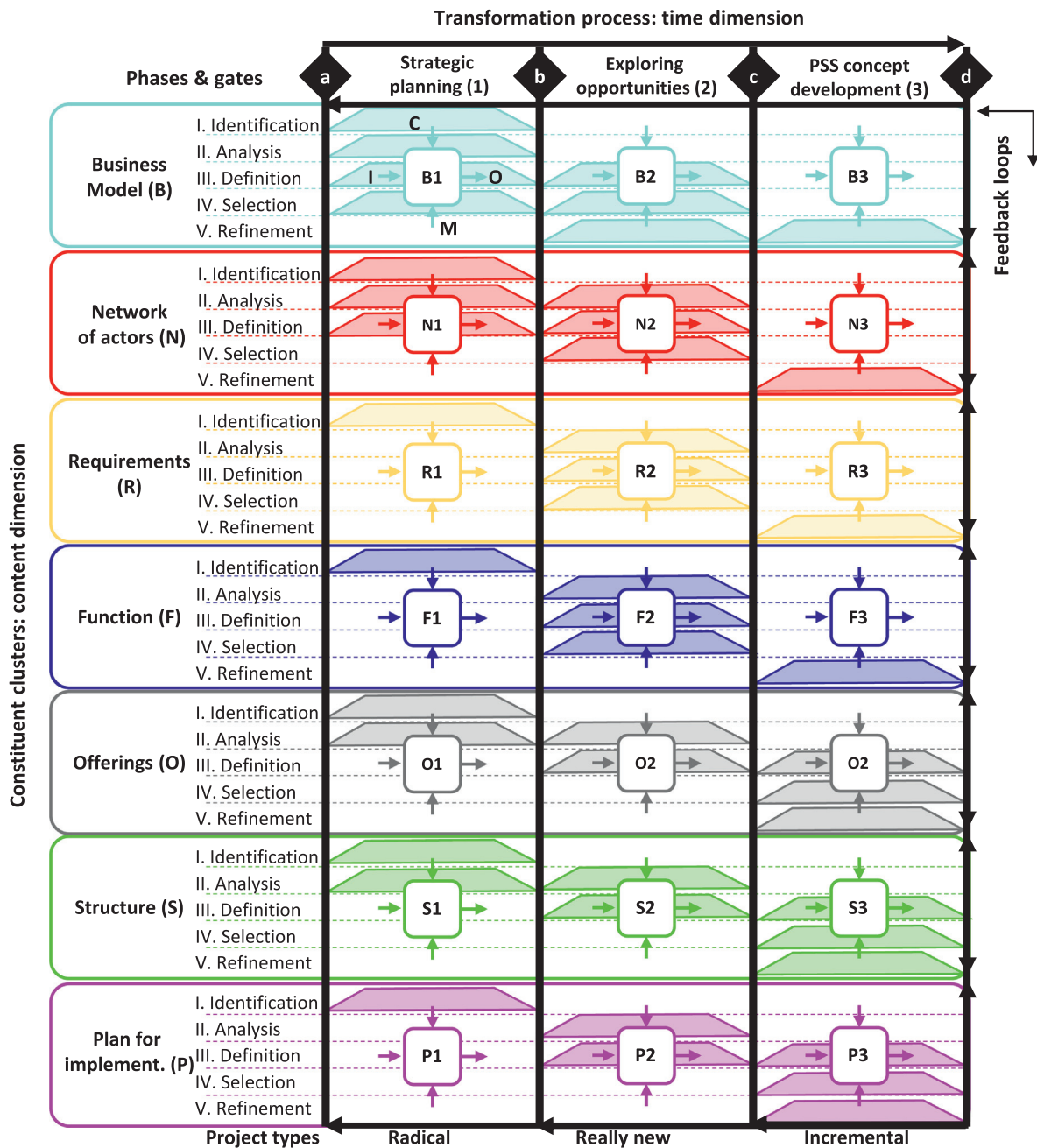
design process might include: (i) studying and comparing the terminology of the generic process model with the existing process; (ii) examining the contents of each of the three main phases and identifying new activities and entities ought to be included in the early-stage PSS design process as opposed to the existing product design process; (iii) identification of industry- and company-specific implications on the process (e.g. for a medical equipment manufacturer, the regulatory processes might need more attention both in terms of the business model and the network of actors); (iv) exploring the possible involvement of certain company departments and functions in the execution of individual activities to design all the required entities; (v) mapping of the newly introduced activities on top of the existing processes to comprehend the level of necessary changes to adopt; and (vi) embedding the instantiated process model in the daily work and acquiring the missing capabilities to design the needed entities.

After the instantiation, the company-specific process model for early-stage PSS design can be utilised for PSS design as well as further instantiated to specific PSS projects. It is envisioned that different parts of the organisation would contribute to conducting activities related to entities of their expertise (e.g., the legal department would take over the regulatory challenges in collaboration with other departments), while the whole PSS design project would be led by a PSS champion, i.e., the person managing the project and coordinating all the stakeholders.

The process of instantiation as well as the evaluation and refinement of the generic process model will be the subject of future research conducted through multiple case studies.

## 5. Discussion

The proposed generic process model considers the PSS design approaches from different backgrounds, namely engineering design,



**Fig. 10.** A generic process model for early-stage PSS design. The activities where the focus must be directed in each phase (e.g. identification of the network of actors in the first phase) are accentuated with trapezoids, therefore devising a temporal sequence of actions for each of the clusters.

business management and information systems and provides a good basis to understand the connection between them by including the entities characteristic of each of the discourses, which was identified as lacking in the contemporary literature.

One could argue that business modelling approaches already include certain entities, e.g. key partners from the business model canvas (Osterwalder and Pigneur, 2009) might seem equivalent to the network entity identified here, however, the generic process model is focused on the delivery process of the PSS offering through the design of actor-networks as a much broader construct, and not merely their identification.

It could further be argued that the process of PSS design never fully comes to a stop, even when the dominant concept is reached, as the conceptual models are a (re-)construction of reality, but the reality

evolves through time. Therefore, the concept should likewise evolve in the background when the offering with fixed architecture is operational in the market. This evolution of a concept can be triggered by an actor's feedback or changed requirements, internal innovations, or when the existing PSS offering has reached its end of use. Therefore, the project that started as a radical project and underwent the full process devised in the generic process model can be restarted via a feedback loop as an improvement project to incrementally ameliorate the concept. The different project types will primarily influence the source and type of input data in the process, varying from the existing customers and already operating product portfolio to new customers with a more exploratory approach. This is an especially important feature of the generic process model for practitioners who are new in the PSS offering market and are still exploring what business model should they operate.

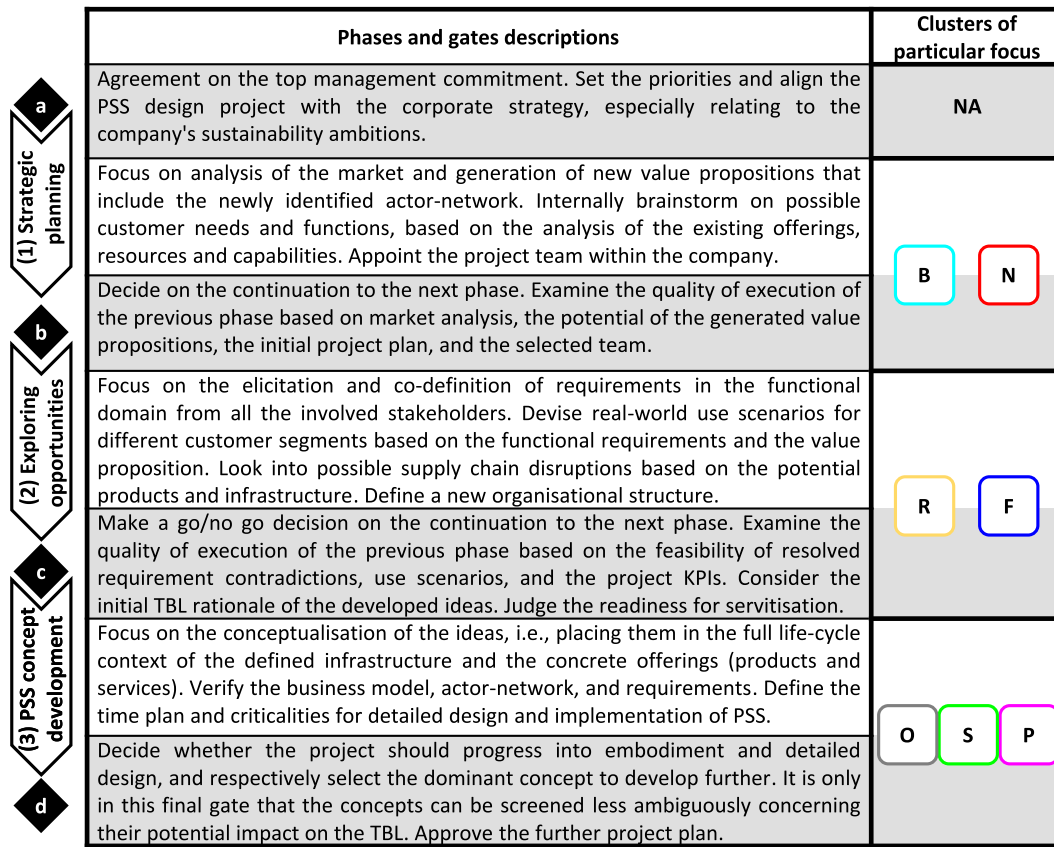


Fig. 11. The typical process of early-stage PSS design with elaborated phases and gates taking account of all the clusters of entities.

The generic process model is envisioned to be applicable for the design of all three PSS archetypes, product-, use-, and result-oriented (Tukker and Tischner, 2006), and in different business environments (business-to-consumer (B2C), business-to-business (B2B) or business-to-government (B2G)), which will be the subject of future research whether the model proposed here can be successfully applied to all the above-mentioned cases.

The entity clusters are represented as stand-alone modules despite their mutual interconnectedness and inseparability (described in Fig. 11). However, a modular process proposed here to reduce execution complexity is deemed a necessary trade-off for pragmatic utilisation in industrial companies without at the same time losing the essence of complex relationships.

Knowing that most approaches to early-stage PSS design are still intuitive and therefore ad-hoc in the industry, the modular input-output architecture of the generic process model split into different clusters enables easier model use by assigning different members of the design team to design certain entities concurrently and others sequentially, thus supporting a variety of readiness level for servitisation in terms of capabilities while also accelerating the design process.

The limitations of the proposed generic process model manifest primarily in its stage-gate structure, which hinders the necessity of cyclical and iterative early-stage design with many feedback loops (Fig. 10) in between the activities and constituent entities. However, the stage-gate structure is deemed necessary to enable more direct pragmatic application in industrial companies, as practitioners should arrive at a defined concept in a reasonable timeframe, without too many alterations to previous phases. For example, the network can be identified in the first phase of the generic process model but can only be selected once the function is selected so that the actors can be assigned to execute corresponding sub-functions. Therefore, even if the network and function selection both happen in the second phase, they do not

necessarily happen fully concurrently. The gates, nevertheless, ensure practical progression and support decision-making throughout early-stage PSS development.

Both the feedback and the entity connection limitations are, however, a conscious trade-off in favour of industrial usability and for easier management of early-stage PSS design process which in most cases involves practitioners from various company departments and different backgrounds.

It has been found that very little consideration in the identified approaches was dedicated to sustainability considerations in early design, and even less to circularity considerations, although PSS represents a significant means to achieving a CE, due to its potential to provide decoupling of value creation from resource consumption. The generic process model narrows that gap by proposing the timing of relevant sustainability and circularity considerations in the early stages of the PSS design, where it is arguable that the considerations made at the earliest phases and concerning the upper clusters in Fig. 10 show more potential positive impact on sustainability, but also the uncertainties concerning the possible rebound effects. Further research inquiry must be dedicated to PSS circularity and sustainability evaluation, especially from the ex-ante perspective in the early stages of design which matters the most, where the constituent entities of early-stage PSS design that influence the TBL of sustainability first must be identified.

## 6. Conclusion

This article provides a comprehensive content analysis of the existing body of knowledge related to the early-stage design of sustainable PSS based on a systematic literature review. The accent is put on the definition of the phases of early-stage PSS design (strategic planning, exploring opportunities and PSS concept development), the constituent cluster entities of early-stage PSS design (business model, network of

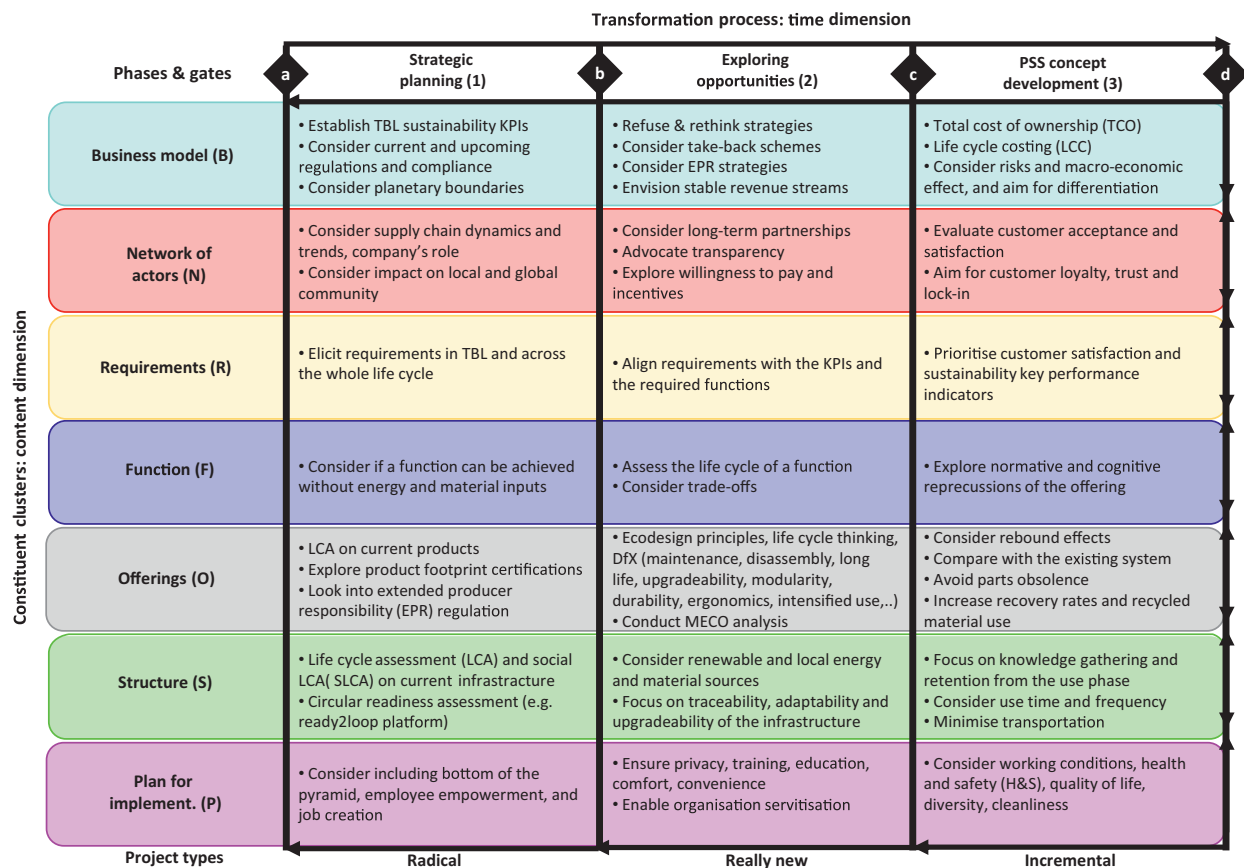


Fig. 12. Relevant sustainability considerations with respect to the seven entity clusters and in the three phases of early-stage PSS design.

actors, requirements, functions, offerings, structure and plan for implementation) as the outcome of early-stage PSS design, and the activities needed to devise each of the cluster entities (identification, analysis, definition, selection, and refinement). Building on the extant but focus-scattered state-of-the-art approaches for early-stage PSS design, the authors propose a much-needed and all-encompassing generic process model for early-stage PSS design in manufacturing companies, adaptive to diverse industrial needs. Due to the inherent inability of a design process to yield more sustainable concepts, this research further proposed relevant sustainability considerations to be made during the design process, mapped on the generic process model canvas according to the development phases and constituent cluster entities. Further research direction involves a more in-depth consideration of circularity and sustainability principles in the early design and evaluation of PSS concepts as well as validation of the proposed generic process in an industrial context. To increase the chances of the widespread general applicability of the proposed generic process model across the manufacturing sector, the authors propose multiple case studies with a recommendation to conduct them in companies of different sizes, different sectors, and with different PSS archetypes (product-, use- and result-oriented).

The main contributions of the paper are: (1) the analysis and characterisation of a comprehensive collection of PSS design approaches currently available in the literature using IDEF0; (2) the development of a generic process model for early-stage PSS design in manufacturing companies; and (3) the mapping of relevant sustainability considerations along the generic process model for early-stage PSS design. The process model proposes a generic approach based on the Rational Unified Process (RUP) characterised by the so much-needed adaptability to individual manufacturing companies, according to their needs in the early-stage design process of sustainable PSS.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

The Supplementary material includes (i) fully detailed descriptive literature findings; (ii) a complete list of the 96 selected approaches including their brief descriptions, focus clusters, backgrounds, and sustainability considerations; and (iii) a fully detailed description of IDEF0 in the PSS development arena. Supplementary data to this article can be found online at [doi.org/10.1016/j.spc.2023.01.020](https://doi.org/10.1016/j.spc.2023.01.020).

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