The Design of Digital Platform Ecosystem Supporting Circular Economy

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Abstract. Circular Economy business models rely on complex data exchange between organizations, which require a supporting digital infrastructure facilitating the circularity-related processes. In a digital platform context, value is generated not by the underlying technologies but by its allied ecosystem: community, users, developers, and integrated applications. These ecosystems come with an intrinsically complex interorganisational structure often overlooked during the development phase, leading to low platform adoption and obsolete platforms in the mid to long-term. Developed through a combined action-research and design science research approach, we propose a framework to support the design and deployment of circular economy ecosystems from a sociotechnical perspective, including practices from the requirements engineering, circular innovation ecosystems and digital platforms literature.

Keywords: Digital Platform Ecosystems · Circular Ecosystems · Sociotechnical Systems Design · Design Science Research

1 Introduction

History demonstrates how technical changes lead to new methods of how value is be created and rendered, which often leads to further disruptions and to new organisational structures [6]. In fact, the digital revolution is a current and continuing process where there seems to be no end to the disruptive capacity of technological innovations, which places digital platforms (DP) and distributed innovation among the main trajectories for innovation [18]. Digital platforms (DP) are transforming virtually all industries today [17,19,1], as their pervasive nature has taken over many of the services we rely on regularly [17]. This happens as well with circular economy (CE). The concept of CE, promoted by the European Union in several initiatives [13,4], can be defined as a "regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops" [7]. To achieve a fully-fledged CE, a systemic perspective where products, processes, information flows, and sharing are fundamental. This perspective, a truly systems-of-systems one as it involves multiple organisations and value chains, is challenged by the information silos that may be formed between the different phases of the product life cycle (PLC), the ineffective interactions between industrial actors and the poor integration of data and information for effective analytics [25]. In this environment, DP can support the creation of more circular ecosystems by involving industrial actors who collaborate in sharing product and process data and information across the entire PLC chain. By unlocking access to this data and information, organisations can more esuriently embrace circular business strategies, resulting in more sustainable business models and overall practices [11,15]. In an industrial setting, a DP acts as both innovation and transaction infrastructure: these platforms make data available from a wide range of industrial assets and devices to enable the building of complementary solutions while supporting marketplace infrastructures that aid distribution and sharing across business partners. Therefore, platforms can perform two central roles: act as a technological foundation and as a market intermediary [18]. However, these collaborative information systems become rather complex when implemented in industrial environments. Large organisations with hundreds or even thousands of employees start to leverage these technologies as part of current business processes and may even develop new ones [18]. However, there is a lack of awareness that a platform's value generation processes depend more on the ecosystem of users, developers, and apps it supports than on the underlying technologies [20]. In the case of a DP used to manage data and information to support CE-oriented decision-making processes chain and fostering a CE-oriented ecosystem, the challenges extend from the difficulty of defining a clear value proposition, to the obstacles of technology deployment and adoption.

In this paper, we describe a framework for the design of a Digital Platform Ecosystem (DPE) supporting CE that considers the multidisciplinary nature of DP and Ecosystems, facilitating the platform adoption by industrial organisations by shifting the design focus to the surrounding ecosystem. From a sociotechnical-focused context, the framework provides guidelines for the deployment of the DP along with its ecosystem, the definition of user and organisational profiles and roles, access, security and privacy policies, trust mechanisms and commitment processes. The framework was developed within the CircThread project[1] and validated in three use cases in three different countries. This paper is divided in the following sections: section 2 focuses on the key characteristics of DP; section 3 describes the adopted Design Science Research methodology; section 4 describes the main results of our research; and section 5 includes lessons learned, as well as topics for future research.

2 Digital Platforms and Ecosystems Design

2.1 Key Characteristics of DP and Ecosystems

DP encompass a broad range of traits that account for their appeal as a business strategy. [29,1]. By supporting multi-sided market connections in a seamless and scalable fashion [29], platforms can drastically reduce transaction costs, which include

[1] H2020-SC5-31-2020 - Building the Digital Thread for Circular Economy Product, Resource & Service Management 2021-2025

matchmaking, profiling, and distribution [1]. Market discovery is achieved through price discovery mechanisms, which often aggregate data from multiple sources, therefore enhancing the experience for different stakeholders [18,29]. DP also have the ability to organise and coordinate technological development and innovation through architectural modularity and appropriate governance structures [27,26]. The vast amounts of data that these platforms can collect and produce are typically made available to a group of unaffiliated complementors, who then use those standard interfaces to create new platforms and services [18]. These services are then made available to users through an app store or marketplace [18]. Additionally, platforms become a main driver for network effects [17,5] – feedback loops that can cause exponential growth (positive network effects) as more users become part of the ecosystem or shrinking (negative network effects) if users and value are not correctly governed, it may cause other users to abandon the platform due to not capturing enough value [17].

Nonetheless, the field of DP research is still prevalent with ambiguity [1,19] as the terms "Platforms" and "Ecosystems" are used interchangeably [20]. [9] advocates fusing the inter-organizational economic, business, and social viewpoints on ecosystems with the intra-organizational technical perspectives on digital platforms. The authors then conceptualise Digital Platform Ecosystems (DPE) as comprising a platform owner that implements governance mechanisms to facilitate value-creating mechanisms on a digital platform between the platform owner and an ecosystem of autonomous complementors and consumers.

2.2 Digital Platform and Ecosystem Design Frameworks

If DP strategy is the engine that drives shared innovation and value co-creation, then Architecture (as the conceptual design for a technological solutions) and Governance are the two gears [26]. Architecture can be seen as a tool for simplifying and specifically describing the relations between components of the ecosystem and reducing complexity [26]. Furthermore, ecosystem architecture encompasses both the platform and complementary applications architecture [26]. How to govern DPE has been a continuing subject of study [19] for many years. The core objective of effective ecosystem governance by a platform owner is to guide and influence an ecosystem rather than directing its behaviour [28] while also ensuring the independence of platform stakeholders, from users on the supply to the consumer side. The definition of ecosystem orchestration techniques by the platform owner, that better leverage and manage the ecosystem's generative character, then become a crucial issue not only for platform design and development processes but also for platform evolution.

Even after the fact that the literature around DP and Ecosystems has not generated much design theory [19], there have been a few attempts to create frameworks, methods, and models to design these sociotechnical artefacts. From their participation in a circular ecosystem project, [12] have developed 3 groups of Circular Innovation Ecosystem principles. [2] also claims that there is little methodical directing for ecosystem design. The authors then synthesise the current works from different point-of-view to develop different typologies and characteristics of DPE. The framework targets ecosystem building by dividing this process into three aspects: goal, ecosystem, and platform modelling. Resulting in the Ecosystem Modelling framework [2] and its introduction in designing Industrial Symbiosis Platforms [3], the Digital Industrial Symbiosis Ecosystem framework has been presented [14]. Furthermore, more generic models outside the scope of circular ecosystems have also been developed, such as the Ecosystem Pie Model [24] and the Platform Design Toolkit [22,21].

3 Methodology

3.1 Research context

The framework for the design of DPE supporting CE was developed within the CircThread project. This project aims to create an Industrial Digital Platform (IDP) to support circular product life cycle decisions by implementing a digital thread specific for circularity-oriented information, linking information generated throughout a product's lifecycle. This IDP can be characterised as a multi-sided platform, where the value exchanged is product information, and the participants' roles are information providers, consumers, and variations of these. In the lack of Digital Technologies (DT) and the corresponding decision-making support across the PLC and its stakeholders, CE presents significant prospects for Europe that are not yet fully exploitable. For this definition, we have adopted the Design Science Research framework, focusing on guaranteeing the usefulness and truth of information systems (IS) artefacts [10]. Applicability is defined by gathering business requirements, such as the CircThread project. The framework-building process itself it's an iterative and creative process consisting of a development/building phase and a justification/evaluation phase. Figure 1 depicts an instantiation of the Design Science Research methodology as applied to this research. This process resulted in the definition of a final artefact – a framework – to be applied in deploying CE industrial ecosystems.

3.2 Research design

The framework was developed using an action-research approach with the participation of the industrial organisations that formed three pilots in the CircThread project. These demonstrators are composed by multiple enterprises in the sectors of home appliances (dishwashers, washing machines and boilers), industrial batteries and photovoltaic panels. The pilots were used as requirements sources for the validation phases.

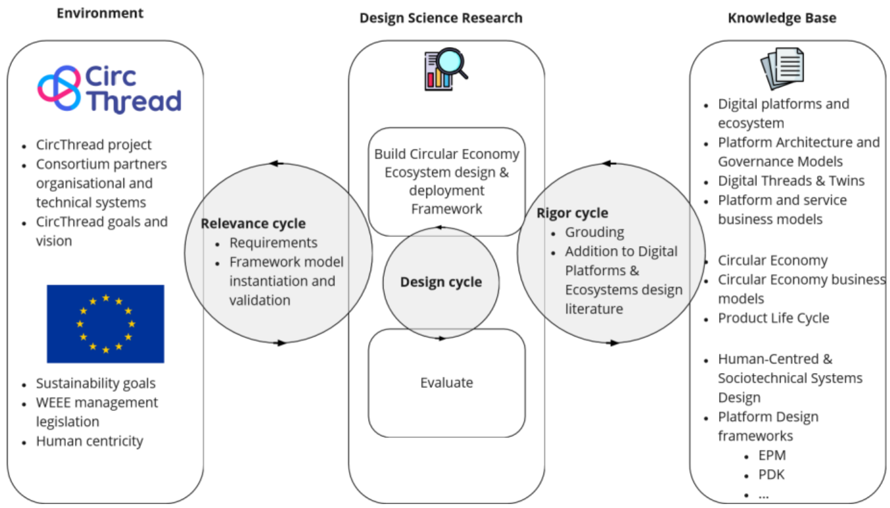

Fig.1: DSR model for the CE Ecosystems design and deployment framework artefact

Defining personas and user stories, together with the knowledge gathered from the scientific literature, an initial scenario for the CircThread DPE was developed. The aim was to learn about the organisational requirements of the partner (who will use the platform, when, for what purposes, and what follows certain actions). By concentrating on "the who, what and when", we could go over and enhance the scenarios and further detail them.

Pilot interactions were conducted in hour-long semi-structured interviews. Through scenario definition, we encountered questions regarding organisational roles and platform interaction. These doubts were then translated into questions for the following interactions with interviews. Due to the framing provided by the project, we did not find it necessary to follow a strict interview process. Partners tended to focus on their needs and specific vision for the platform without much need for leading questions. Even so, the questions posed focused on the organisational requirements and the vision for governance models.

With precise scenarios of platform usage, we began to document platform interactions adopting intra-organisational perspectives by modelling internal business processes and inter-organisational perspectives by understanding ecosystem dynamics and informational dependencies between actors and product lifecycle stages. With a complete mapping of the requirements for the ecosystem, we were able to define a set of recommendations on conceptual DPE architectures and governance models, as well as strategies for deployment leading to a minimum viable ecosystem.

4 Results

4.1 Framework Components Overview

In this section, we detail the components of the developed framework, also shown in Figure 2.

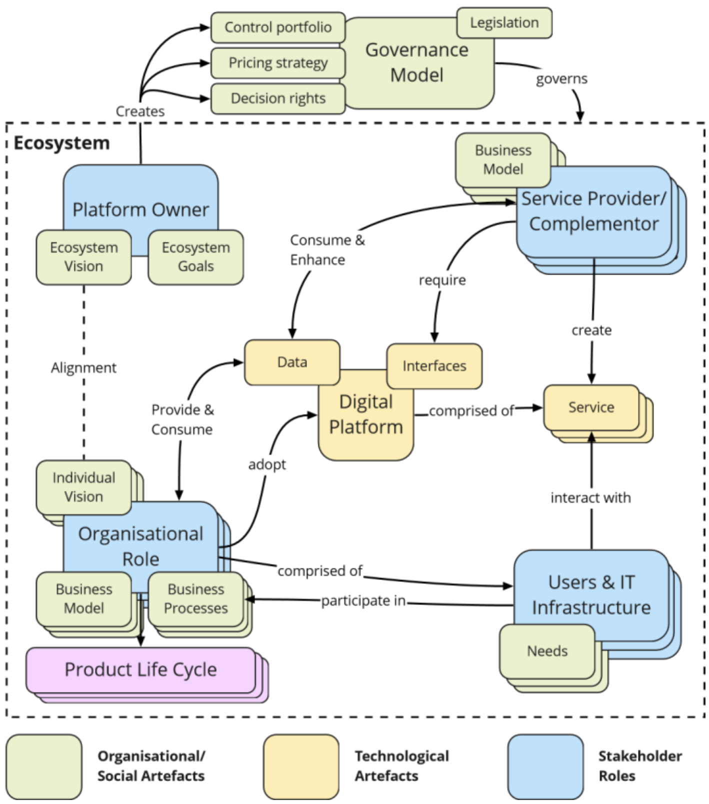

Fig.2: CE Ecosystems design framework

Ecosystem: The ecosystem (encircled by the dotted line in Figure 2) comprises the technical and organisational artefacts and the multiple stakeholder roles. In this context, the DP becomes the central infrastructure for the ecosystem.

Digital Platform: The DP stands at the core of the ecosystem, acting as an orchestrator by providing the main mechanism for stakeholder value co-creation. The platform acts as the technological infrastructure that facilitates the sharing of data between the stakeholders. This sharing leverages the same interfaces complementor use to interface with DP data storage and retrieval solutions and build new DP-based services.

Platform Owner: The platform owner's role is crucial for the design and maintenance of the ecosystem. The role can be fellfield by a single organisation, a collection of individuals or organisations, or even a coalition of organisations that share an interest in developing the ecosystem.

Organisational Role: Composed by the archetypes that adopt the DP into their business processes to create new business models or transform existing ones. Each role gathers value from the ecosystem in different manners that must be elicited and aligned with the Platform Owners for a common, shared vision and design vocabulary. These archetypes often relate to their business model and/or product life cycle acting phase.

Product Life Cycle: Product life cycle phases are specific states that products go through. Organisational roles can have activities related to multiple business models in one or several life cycle stages. Mapping these stages is crucial since it will enable the ecosystem designer to develop models and organisational responsibilities, enhancing the design's quality. In CircThread's specific case, we were able to map the life cycle phases and the progress between them, in which any of the considered appliances, as an example, can be at any point.

Users & IT Infrastructure: Represents the users of a DP-adopting organisation. Users can be any entity that interacts with the platform, from workers to cyber-physical systems, IT infrastructure or even software.

Service Provider / Complementor: Complementors are the core generative engine of the DP. Leveraging the DP resources - data, interfaces, and core services - complementors develop and integrate original, third-party services that are deployed into the current DP instance and have facilitated access to the platform's ecosystem of users. The nurturing of stable relationships with service providers/complementors by ecosystem designers is crucial to incentivise the creation of new and innovative services and push for platform evolution over a medium to long time frame.

Governance Model: As previously discussed, by applying [26] governance pointers, the platform owner and designer should be able to describe and architect the governance model more accurately. Furthermore, it becomes critical to consider in-place regulations surrounding CE, DP, and all the (physical and virtual) assets to be managed by these systems, as they have a significant impact on all aspects of development and implementation.

4.2 Information Ecosystem and Roles

An informational role is a role involving specific tasks related to the creation, modification, or use of information. Six types of informational roles were identified and characterised: *provider/producer, consumer, complementor, disseminator, regulator, and enhancer*, with each platform role corresponding to multiple informational roles. A supplier can provide product design and manufacturing information while consuming information provided by recyclers during disposal stages. Roles are further classified based on 5 characteristics: (i) main interest: what are each role's primary motivations for using the platform; (ii) specific context: the specific benefit to how the platform is used and how value is generated; (iii) PLC conditions: what are the required PLC specificities or conditions for the platform to be implemented; (iv) skill requirements:

what sociotechnical conditions must be met so that users of the specific role can fully engage in ecosystems; and (v) dependencies: in which ways can different roles become complementary to one another to potentialize value exchanges.

4.3 Using the framework for deploying and configuring a DPE

Characterisation of organisational and user roles: The initial step for applying the framework in the DP design requires the identification of the Platform Owner, that defines the vision and objectives of the platform, designs business models and ecosystem, and all the Organisational and User Roles, based on business models and product life cycle phases. The implementation of a DP-based architecture will also facilitate the development of business strategies that require a robust and scalable (in technical and business senses) digital infrastructure. Hence, platform-based business model design should comprise a process where the ecosystem designer iterates over the ecosystem's value proposition for each organisational role. One common approach for this process is using user stories that facilitate the gathering of requirements and core functionalities [16].

Creation of shared ecosystem vision and business processes: Having established the complete set of roles to co-exist in the DP, a shared ecosystem vision can now be developed, leveraging the perspectives of the user organisations and internal business processes and data needs. It is also crucial for stakeholders to agree on an integrated vision for the DP as it sets the starting ground for crucial DP critical design decisions.

Going further, the contextualisation of (i) users and needs; and (ii) the adopting organisation's business processes which the DP will enhance, also become an important step for a comprehensive vision definition. According to the specificity of these descriptions, it might become useful also to include depictions of business processes and platform interaction—using a formal notation, such as Business Process Model Notation [8]. With detailed system usage scenarios and diagrams, the platform owner is now aware of these organisations' data and information needs.

Development of collaborative networks, ecosystem dynamics and initial governance model: This phase identifies ecosystem dynamics and requirements between organisational roles to generate an initial ecosystem governance model. Embracing a wide ecosystem lens that takes the organisational and informational functions previously defined as starting points, together with the categorised product life cycle phases, the platform owner can map ecosystem dynamics and define a robust strategy for managing the ecosystem to deliver value for all the stakeholders. To support this process, we propose creating an Information Ecosystem model to represent the complex set of data dependencies connecting different actors and also the different stages of the product life cycle. Figure 3 can be viewed as an example of creating instances of Information Ecosystem models. With this model, the ecosystem designer can extract the organisational actors and the consumed information from the product life cycle phases and should now focus on collaboratively developing the ecosystem's governance model.

Development of platform governance and conceptual architecture: With core services that make up the initial platform value proposition defined, design efforts must now be shifted to the definition of the technical interfaces that allow complementors to develop and integrate their service offers into the platform's ecosystem. Additionally, boundaries between services and data that belong to the developer or to the platform need to be established and integrated into the platform's ecosystem guidelines. While the common understanding is that the openness of a DP (concerning its governance model, for complementor innovation), the more appealing it is [12], increasing the chances of network effects exploitation, the specificities of each case must be taken into consideration. Platform openness can diminish the influence of the platform owner, causing changes in the platform and its ecosystem that were unforeseen in the early design stages. Relying on the nature and objectives of the DP, governance models can widely vary in their degree of openness and must be carefully and collaboratively designed.

Development of platform deployment strategies: Existing strategies provide effective insights for ecosystem designers to collaboratively develop a deployment strategy that effectively adapts for DPE. [23,17] summarises common strategies for platform deployment: (i) single target group, focus on a particular target group or segment of the market; (ii) subsidising strategies that rely on incentives to boost the mass of a single side of the market in order to create value for another, up until value is naturally generated and exchanged and subsidising is no longer needed; (iii) platform envelopment that leverages connections with established DP by combining its own services and functionalities with the target platform packaging more complete offerings; (iv) exclusivity agreements by signing exclusivity agreements on one market side can be sufficient to attract other users on both market sides; and (v) side switching where a two-sided platform market is transformed into a one-sided market by developing market strategies that fulfil both sides needs at the same time.

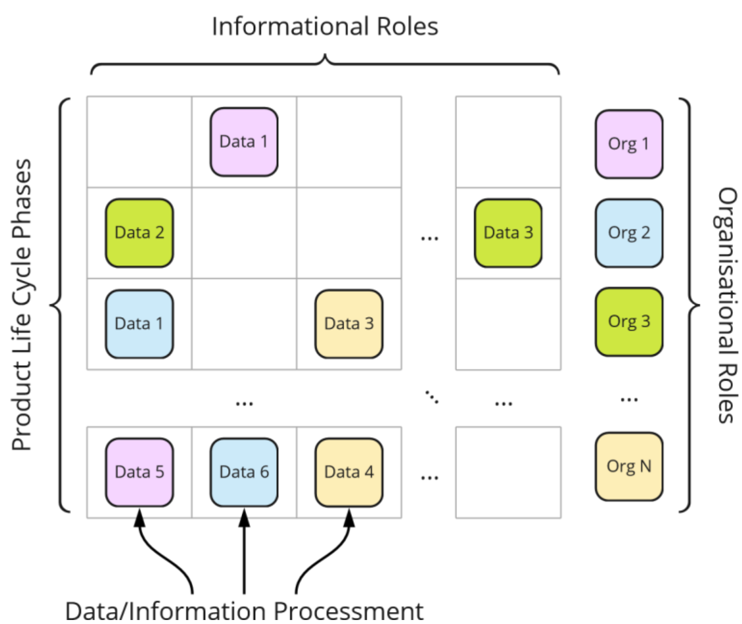

Fig.3: Information Ecosystem model creation tool

5 Conclusion & Future Work

The lack of insights from the literature into the design of DP and DPE lead to a state-of-the-art where industrial platforms and platform services have become ephemeral, contributing to the lack of adoption. The growing adoption of circular practices in the industry can become the impulse that platform-based business models need to solidify their stay in business-to-business markets further. From this perspective, and by relying on a combined action-research and design science research approaches, we presented a framework that is both rigorous and flexible to serve as a reference for platform owners and developers to guide the early development stages of thriving DP-based Ecosystems.

Regarding future work, we can identify that there is still space to accommodate more constructs to cater to specific industries. The CE design and deployment framework was also validated in the CircThread project, where it was developed. Validation in other CE DP-based Ecosystem development projects would further support the many components of the framework, feeding the cycle of build design and evaluation.

Additionally, even though we provide a detailed explanation of user roles, the framework, as well as practical methods to go through the different design phases and validate requirements from ecosystem participants, we welcome the development of other real-world Requirements Engineering models and methods that might better fit other projects. The addition of transparent and effective models for developing, documenting, and validating governance models would also greatly benefit the developed framework.

Acknowledgements

This paper is supported by European Union’s Horizon 2020 research and innovation program under grant agreement No. 958448, project CircThread (Building the Digital Thread for Circular Economy Product, Resource & Service Management) and the Ph.D. Grant UI/BD/152565/2022 from the Portuguese funding agency, FCT-Fundação para a Ciência e a Tecnologia.

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