Product Line Engineering in Smart Governance Systems

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Keywords: Configuration, Feature Models, Smart Governance, Software Product Lines, Software Reuse.

Abstract: Smart governance systems are used to develop smart and sustainable cities. Small municipalities are users of these systems. However, creating individual and custom systems for each municipality is costly and often unfeasible due to the limited resources of local governments. Developing a modular and configurable system could help reduce costs, enabling municipalities to tailor solutions to their specific needs without requiring custom developments. Software Product Line Engineering (SPLE) can make this possible by fostering software reuse, and creating a set of adaptable systems that share common features. Nonetheless, applying SPLE in the smart governance domain remains challenging and, so far, there is no applications of SPLE in this area in the existing literature. We propose an Smart Governance Product Line (SGPL), based on a multi-level configuration architecture for the customization of solutions in the smart governance domain. Based on the SGPL, we also present a prototype configurator for customizable governance systems that has been used in a case involving three municipalities with different needs. The tool was materialized with configurations of the existing *Decidim* governance system. The prototype demonstrated its usefulness in deploying in an easy and automatized way adapted configurations to the municipalities' needs. Furthermore, the case study suggests that this approach could evolve into a general framework to support different software systems and components for providing a comprehensive smart governance platform tailored to institutional specifications.

1 INTRODUCTION

Smart governance boosts the quality of public services and provide smart management (of territories and societies), through a collaborative government, open to all the stakeholders. Introducing smart governance requires the collaboration of different parties. However, the variety of stakeholders with different and sometimes conflicting interests introduces by a complex challenge (Tran et al., 2019). The joint use of 'smart' and 'governance' aims at maximizing positive results by means of intensive use of Information and Communication Technology (ICT) (Nastjuk et al., 2022). Materializing smart governance is complex, as it involves multiple systems and services that are required to interoperate. A smart governance, is an ecosystem that presents a great variability due to the different needs of multiple stakeholders, as well as different software systems and services. Additionally, governance processes and public services in small municipalities may not be the same to those in big cities, or those in a regional or state level (Fajar and Shofi, 2017; Ojo et al., 2007). Smart governance is key in the 2030 Agenda to achieve sustainable cities (Ependi et al., 2022), facilitating the implementation and configuration of these systems is a relevant issue.

Software Product Line Engineering (SPLE) is used to manage software variability by focusing on the systematic production and reuse of shared assets across related products, thus favoring variability and reusability (Achour et al., 2011; Felfernig et al., 2024). A Feature Model (FM) represents all possible configurations of a Software Product Line (SPL) in a compact way (Felfernig et al., 2024; Pohl et al., 2005). To the best of our knowledge, SPLE has not been applied in the smart governance context so far.

In this paper, we propose a general Smart Governance Product Line (SGPL) approach that considers the main features and needs of smart governance. The SGPL would allow for the generation of

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Muñoz-Hermoso, S., Olivero, M. A., Domínguez-Mayo, F. J. and Benavides, D.
Product Line Engineering in Smart Governance Systems.
DOI: 10.5220/0013522200003964
In *Proceedings of the 20th International Conference on Software Technologies (ICSOFT 2025)*, pages 262-272
ISBN: 978-989-758-757-3; ISSN: 2184-2833

smart governance platforms adapted to each individual need by reusing commonalities. The SGPL approach is supported by a configuration tool named *InGoverkno* (configurator for INtelligent GOVERnments KNOwledge-based platforms). Such a tool allows the configuration of desired features for a smart governance system. The configurator is based on an FM that collects the common features of smart governance. The FM allows to study the variability of this SGPL, through the configuration of the different alternatives. Once the desired smart governance has been chosen, the configurator deploys a customized smart governance platform using the features available in the chosen platform (i.e., *Decidim*[1]). This configurator was applied to the needs of three different-sized local governments suggesting that the case study results would facilitate the deployment of smart governance solutions.

Our approach contributes to this area by (1) exploring the variability of smart governance systems, (2) defining a FM for smart governance, and (3) developing a configuration tool that enables the automatic deployment of customized systems.

This paper is organized into different sections: Section 2 reviews background and related work. Section 3 presents the SGPL. An FM summarizing the features and constraints is proposed in Section 4. Then, Section 5 outlines the application of our configuration tool, which is used in a case study in Section 6 involving three municipalities. Finally, Sections 7 and 8, discuss and summarize the findings, and propose future work.

2 BACKGROUND AND RELATED WORK

Electronic governance (e-governance), uses ICT to enhance public services and encourages citizen participation in the decision-making (DM) processes (Grigalashvili, 2022). Thus, the e-governance and its DM processes are the basis for implementing participatory processes such as public consultations or participatory budgets (Bherer et al., 2016; Boudjelida et al., 2016).

Smart governance implies e-governance in which smart technologies (e.g., artificial intelligence [AI]) are jointly applied with civil society collaboration for the co-creation of quality public services and promote optimal DM (Parycek and Viale, 2017; Ruijer et al., 2023). Therefore, electronic collaboration (e-collaboration), defined as '*working together as a team in a particular situation to solve problems using technologies*' (Abdullah et al., 2019), plays a key role in smart governance implementation. Since smart governance is a recent and multifaceted field, and still remains complex to handle, it is rare to find any technical progress (Nastjuk et al., 2022), and most existing applications are more focused on the field of democratic or collaborative e-governance rather than on smart governance.

Among the existing e-governance systems, *Decidim* and *Consul*[2] highlight for their wide range of functionalities and for covering all stages of the public policy cycle (Deseriis, 2023). Furthermore, it was reinforced by an overview of websites of 20 existing applications. Some of these features are also useful in the smart governance context. We focus on *Decidim* platform as it is open source and has flexibility and diversity of components. Furthermore, its design is focused on public institutions being used in relevant municipalities such as the city council of New York, Helsinki and Barcelona, as well as the European Union, among other institutions. In addition, it considers participation and collaboration in a broader way. So that its participation feature could be applied in any organization, and be specialized in specific participatory processes for institutions. Like the vast majority of platforms, it lacks features that enhance knowledge and collective DM by applying group DM and AI techniques, that they could move from 'Democratic Governance' to 'Smart Governance'.

The configurability and variability management of information systems is important. SPLE together with the FM modeling method, enable software products and services to be adapted to the needs of the organization and its stakeholders (Felfernig et al., 2024; Pohl et al., 2005).

The e-collaboration field has an inherent complexity that is increased since its requirements and needs vary according to the domain of application and the type of organization (Munkvold and Zigurs, 2005). Therefore, regarding the e-governance field (which involves e-collaboration), it also supports a great variety of requirements related to the governance processes, the institutions and its stakeholders (Fajar and Shofi, 2017; Ojo et al., 2007). Thus, considering the high variability of those systems, a multi-level configuration approach is also suitable to manage their configurability (Reiser and Weber, 2007). However, we have not found any approach that specifically addresses the problem of configurability in smart governance or in the e-governance context. As evidenced in the literature review and highlighted in (Cledou and Barbosa, 2017), there are few studies that address

[1] https://decidim.org/

[2] https://consuldemocracy.org/

variability and SPLE in the general electronic government (e-government) domain, so this is an area that needs to be further explored.

We have identified some studies related to the e-governance field. Even though they do not focus on improving configurability, some studies promote the development and adaptation of these e-governance systems to different needs by means of SPLE (Achour et al., 2011; Cledou and Barbosa, 2017; Fajar and Shofi, 2017). An FM is proposed in (Debnath et al., 2008) using a broader vision and considering the features of e-government systems. The FM also considers establishing a division by front-office or back-office software, and another by applications typology, such as Government to Government (G2G) or Government to Citizen (C2C). In (Fajar and Shofi, 2017) the authors further distinguish products for central or local governments. It is appropriate as the latter offers public services related to city government, quite different from those offered by the state government. SPLE is also applied in some particular use cases such as the one proposed in (Lima et al., 2014) for content management systems (CMS).

3 SMART GOVERNANCE PRODUCT LINE

So far, no single system fully supports smart governance services because of their complexity and the diversity of data required from the organization. Therefore, the services to be developed will need to interoperate with the organization's general and e-government legacy systems, presenting a high variability and complexity (Fajar and Shofi, 2017).

The SGPL involves a vast variability. Managing an SPL and its customization in a context of large variability and multiple features is challenging if using a flat configurability (Clark et al., 2017). However, a multi-level approach favors configurability and reduces the complexity of managing the variability (Clark et al., 2017; Czarnecki et al., 2005; Reiser and Weber, 2007).

3.1 Multi-Level Configuration Architecture

A multi-level approach enables division and organizes the configuration into different levels. Each one of these levels is related to a different area such as system parts or requirements groups, facilitating the configuration, customization, and reuse of the services (Clark et al., 2017; Czarnecki et al., 2005).

SGPL considers a fourth-layered configuration as shown in the Figure 1: Level 1 (Process), collects the variability of the business processes for each individual governance collaborative event. Level 2 (Model), is proposed as an abstraction layer to assist in implementing different smart governance models. These first levels manage the variability of the business logic of collaborative processes. To divide the complexity we opted for model two abstraction level since collaboration is a main pillar of smart governance (Nastjuk et al., 2022; Purba and Arman, 2022). Thus, the specific smart governance domain is considered a specialization of the general e-collaboration domain. The left side represents the configuration of the general e-collaboration domain, and the right side is the specialized ('white triangles') configuration of the smart governance domain.

Level 3 (Platform), represents the set of features characterizing the deployed customized smart governance system. Finally, level 4 (Organization) is used to orchestrate those particular features of the system for the specific organization. Whereas these first two are common to any organization, the latter two refer to the software system that supports the smart governance instance for each individual process and specific organization.

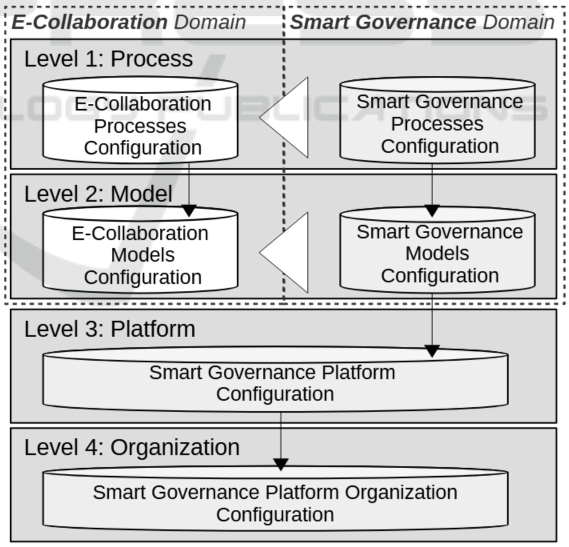

Figure 1: Multi-level configuration architecture.

The multi-level approach contributes to a more precise and easier customization, as several organizations can be customized at once. In addition, the configurations are inherited through the levels from top to bottom. The whole system could be updated when acting on levels 1 and 2 of the configuration. Just by modifying level 3, it can be modified those features that globally affect the behavior of the whole system.

Finally, it is possible to customize any particular organization by only modifying the differential features at level 4.

Level 1: Process. The participatory processes are subject to citizen participation and collaborative governance regulations. Since there are different regulations and procedures depending on the country and territorial scope of the institution, a way to configure the participatory processes is needed. Therefore, level 1 defines and characterizes these process models, and allows their adaptation to the needs of each organization. (e.g., a certain process might be modeled for collaborative agenda setting, whereas another might be modeled for participatory budgeting).

In the *E-Collaboration Processes Configuration* the common e-collaboration features of different types of collaborative processes are set (e.g., whether the process includes DM, which stakeholders can participate, how the final decision is made, the duration of the process, etc.). The *Smart Governance Processes Configuration* allows specialized process typology for the smart governance domain (e.g., citizen consultations or surveys) and configuring their specific features. These process configurations are materialized in the next configuration level 2.

Level 2: Model. Models are used as a structure or reference, to be reused or adapted. The models of e-collaboration and smart governance refer to a set of principles, structures, processes or mechanisms that guide how decisions are taken. Those processes are already considered in Level 1. However, the same process may vary according to the kind of organization, its scope, or its goals. The idea of having a *E-collaboration Models Configuration* and a *Smart Governance Models Configuration* is to help institutions and organizations define their structure and DM behavior. Consequently, these models would allow reusability and adaptability of already existing processes (relations represented by 'black arrows'). These two levels enhance dynamic variability, as they enable a system in production to meet new needs by configuring new types of collaborative processes or new governance models.

Level 3: Platform. Previous levels characterize the smart governance models with their associated processes in software platforms and might be seen as a back-office configuration. This Level 3 instances specific pre-configured smart governance models with their process ('black arrow') that can be adapted to the specific smart governance platform to be customized and deployed. This *Smart Governance Platform Configuration* outlines the software particularities to be used by specific organizations, allowing the customization of a product from the SGPL that supports the chosen customized smart governance services (i.e., a set of smart governance models, and its associated processes). Thus, a unique software platform can offer smart governance services to a set of organizations. This configuration level also fosters the identification and use of common and reusable assets (i.e., components, tools, libraries and other artifacts) to be later employed through application engineering to generate the customized platforms.

Level 4: Organization. Previous levels detail the configurability of those features that can be offered, whereas this level allows the customization of those chosen features. Taking account the multi-organization approach of level 3, in level 4 each organization can tailor a deployed platform according to their requirements. Those requirements consider general and specific features of the governance model and its processes. For instance, some municipalities may want their participatory processes to be binding, whereas others may only want them to be consultative. It also applies to specific characteristics of the organization, and its participatory processes, such as the duration, participation requirements or restrictions, among others. It will also be the level where the user interface of the platform can be adapted to the needs of the organization. Consequently, this customized *Smart Governance Platform Organization Configuration*, constrained from the general platform configuration ('black arrow'), makes up the complete platform-specific configuration for any particular organization.

3.2 Features

Below we briefly describe, organized by groups, the most relevant features desirable in the smart governance systems and services. They are based on the principles, drivers, key aspects, regulations, and functionalities that we have identified in our research about e-governance and smart governance. Furthermore, they have been endorsed and adjusted based on the analysis of the features of existing e-governance platforms and the feedback received from real users on e-governance needs according to the case study carried out (Section 6).

Core Features. They are the main features to support the core functionality and business logic of smart governance managed at levels 1 (Process) and 3 (Platform) of the configuration. Since collaborative governance and shared DM with civil society are key for smart governance (Ependi et al., 2022; Nastjuk et al., 2022; Purba and Arman, 2022; Ruijer et al., 2023), these features include the logic necessary for stakeholders to interact with the system on a given topic by providing and sharing information and knowledge to solve a problem or make a decision. Furthermore, the evaluation of the results of decisions, projects, and services by stakeholders will provide feedback that facilitates appropriate changes to improve results, transparency, and accountability (Hasan and Rizvi, 2021; Parycek and Viale, 2017; Valle-Cruz et al., 2020). They are the basis of the collaborative processes implementation.

About Techniques, Technologies and Methods. Intelligent and intensive use of data and ICT are key in smart governance. Thus, data analysis (DA) fostered with knowledge management (KM) capabilities allows obtaining relevant information for achieving effective evidence-based policies and intelligent DM (Hong and Lee, 2023; Parycek and Viale, 2017). DM techniques can improve individual and group decisions, as well as favor negotiation and consensus building (Tran et al., 2019). AI techniques can be applied to DA, KM and DM, improving the co-production of quality public services (Hong and Lee, 2023). Techniques such as machine learning and deep learning allow extracting useful information and knowledge to improve DM (Hong and Lee, 2023; Hasan and Rizvi, 2021). Thus, this features group, managed by level 3 of configuration, favors collective knowledge management from the different data sources and stakeholders.

About Guarantees. Since legal framework and ethical principles are key aspects (Parycek and Viale, 2017; Pereira et al., 2018), these platform's features (level 3) enable rules related to norms, policies, procedures and ethical values of the organization, so that actions and decisions are within the legal and ethical frameworks that affect the organization and the people related to it. To accomplish principles of transparency and accountability of e-governance (Abu-Shanab, 2015), features are contemplated to support real-time information on the collaboration process and DM; as well as on the criteria used to choose certain options (explainability) and their results (Dwivedi et al., 2021).

About the e-Collaboration Model. These features are related to the e-collaboration model used in smart governance and addressed in configuration level 2. They aim to favor agile and continuous interaction between and among the stages of the collaborative processes providing value incrementally and iteratively (Parycek and Viale, 2017; Valle-Cruz et al., 2020). Since a knowledgeable citizen will influence more effective DM processes (Tiwari et al., 2023), its qualification may be reflected in the weight of collaborative outcomes and DM. A comprehensive and multi-level approach across the policy cycle and decision levels maximizes the benefits obtained (Hong and Lee, 2023; Tiwari et al., 2023; Valle-Cruz et al., 2020; Wirtz and Müller, 2023). Furthermore, multi-organization support enables collaboration of several organizations to solve common problems, fostering intergovernmental collaboration (Hasan and Rizvi, 2021). A data-driven model together with smart assistance, through AI and DM features (above mentioned), fosters performing automated actions and evidence-based DM (Ju et al., 2018; Parycek and Viale, 2017). All previous benefits can be enhanced with networked processes to obtain greater knowledge, through aggregation relationships to create more complex processes composed of others, affinity relations between similar processes, as well as information or chronological dependencies.

About the e-Collaboration Process. Features must be considered (level 1 of configuration) to regulate the functionality of collaborative processes, the adaptation to the specific typology of participatory processes, and the different phases of the policy cycle (i.e., policy strategy, agenda setting, policy formulation, policy implementation and policy assessment (Hong and Lee, 2023; Valle-Cruz et al., 2020)). Thus, these features allow characterize the most common types of participatory processes contemplated in the different regulations on citizen participation (Bouzguenda et al., 2019; Parycek and Viale, 2017; Yusuf et al., 2019). They also allow enabling the DM stage in collaborative processes, and the assessment of their outcomes. Other specific features are contemplated for the finest adjustment of processes working.

4 FEATURE MODEL

A Feature Model (FM) is a structured representation of those features that characterize a system. These features define the functionalities and key properties, which are classified as mandatory, optional or alternatives. Defining the FM for the SGPL helps in visualizing how the features are orchestrated and which of them are common for the products of this SGPL.

The FM that characterizes the SGPL approach considers the multi-level configuration architecture integrating their levels to obtain a family of customized products down to the specific platform of the organization. Although this is a single FM, for greater clarity we present the subtrees related to each level, in a descending order respecting the natural hierarchical order of the FM. The features outlined in the subsection 3.2 are specified and represented below.

4.1 Feature Model - Level 3 & 4

Figure 2 represents the general features of the smart governance platform, showing collapsed groups of features related to the other configuration levels 1 and 2. The FM initial root represents the *Smart Governance Platform*, which has *E-Collaboration Common Services* and *Smart Governance Services*. Furthermore, on the one side, a *Multi-Tenant* architecture can be chosen. It defines whether the platform is going to be used by different organizations (and customized for each one) or an independent platform will be considered for each organization. On the other hand, the group *Graphical User Interface* (GUI) is optional defining if a GUI is required or if an existing external interface is used. If the system GUI is selected (collapsed in the figure), then the organization might choose between a *Web Platform*, a *Mobile App*, or both; for increased interoperability and accessibility from any device. On these levels, the features of the final software platform are configured in a general way and in specific organizations that use the platform.

Regarding *E-Collaboration Common Services*, *Collaboration* and *Decision-Making* are considered core features. Both are mandatory in any configuration, because these general services are necessary to accomplish any process related to smart governance. Nevertheless, these must be customized to adapt to the organization's needs, through their features and subgroups. *Assessment* functionality (shown collapsed) can be selected to accomplish *Results Assessment* of processes and decisions, or *Stakeholders Assessment*. In smart governance, these services will enable public policy evaluation citizenship processes.

Technical Capabilities (some of which are required by other models and processes), enhances addressing complex collaboration and DM problems. This is achieved by including technical capabilities for data analysis (*DA Support*), knowledge management from relevant data (*KM Support*), and individual and group knowledge-based DM (*DM Support*). *AI Support* is required to support these capabilities.

To ensure accountability for the organization and its stakeholders, the *Guarantees* features *Transparency*, *Ethics Control*, and *Legal Control* (shown collapsed), play crucial roles by activating mechanisms that provide full real-time information, promote regulatory compliance within the domain and the organization, and uphold ethical standards. These functionalities require the activation of the *KM Support* feature, which allows the system to manage the ethical and legal rules modeled and perform inference tasks effectively.

For domain-specific *Smart Governance Services*, it is mandatory to establish if one or various *E-Collaboration Model* (the root for Level 2). Its cardinality in a range *1..n*, increases the variability, allowing the definition of a set of models, and for each of them, different types of processes. That is, different services depending on the models and types of e-collaboration processes that they implement. Furthermore, *Systems Integration* is also are mandatory. Within this group, the feature *Organizational Services* (shown collapsed) is mandatory, as the system must interoperate with other existing information systems in the organization (Nastjuk et al., 2022; Pereira et al., 2018) such as *E-Census* for controlling user access, or secure *E-Voting* services.

To address comprehensive smart governance throughout the entire public policy cycle (Valle-Cruz et al., 2020), specific services for collaboration in urban processes and projects are desirable. This is achieved by activating the *Urban Process Services* and *Urban Project Services*, with the latter being essential for collaboration within the former. Urban processes typically progress to the implementation phase, where ideas are developed into proposed solutions [3].

4.2 Feature Model - Level 2

Level 2 represents the e-collaboration and smart governance models. In Figure 3, the variability of these models is represented. Except for the selection of at least a *E-Collaboration Process* to be included in the model, all features are optional. They enhance the capabilities of the core model established in *E-Collaboration Common Services* from other levels.

The *Project-oriented* feature enables e-collaboration at project, and project phase level (required if *Urban Project Services* are activated). *Networked-Processes* allows the creation of more complex collaborative processes based on simpler ones, or to relate processes with each other, forming a network to interoperate between them.

The *Multi-Level* feature enables collaboration across the organization's DM levels (strategic, tactical, and operational). Together with the *Multi-Organization* feature, it supports complex, cross-organizational processes to address shared problems, requiring the activation of the *Multi-Tenant* feature.

[3] An urban process generally advances projects during the implementation phase, transitioning ideas into proposed solutions (Tran et al., 2019).

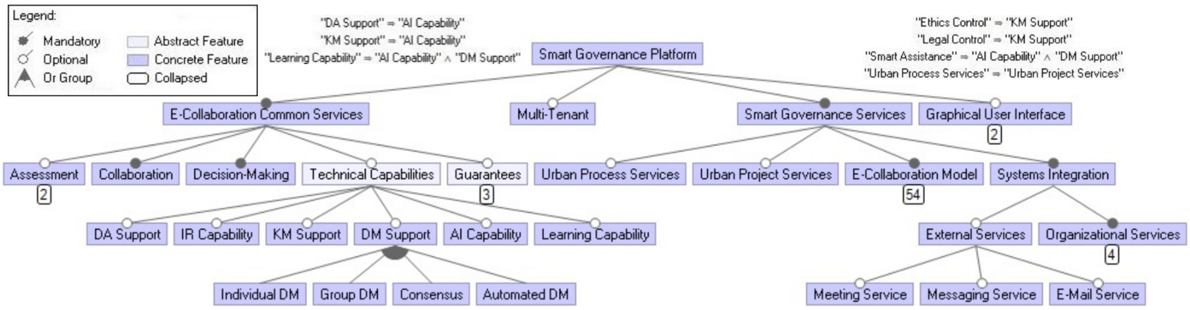

Figure 2: General FM for smart governance (level 3 & 4).

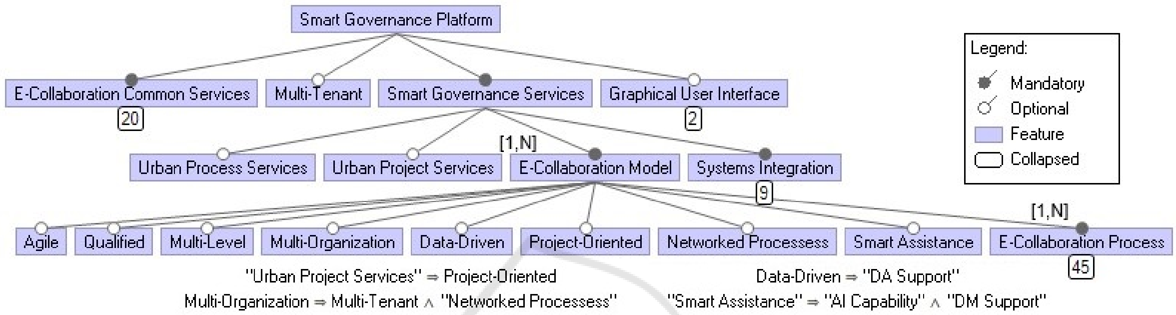

Figure 3: FM for e-collaboration model (level 2).

The *Agile* feature introduces feedback between the different phases. Together with the previous one (*Multi-Level*), they facilitate dynamic collaboration throughout the public policy cycle.

The *Data-Driven* feature requires the activation of *DA Support* to obtain relevant data. Enhanced by the influence of the expertise and qualification of the collaborators (*Qualified* feature), in the DM process, it allows knowledge to be promoted in the final results of the decisions. Both features contribute to a citizen-centric government. Finally, *Smart Assistance* is envisaged, to support informed and effective DM, through the activation of (*AI Support*) and DM techniques (*DM Support*).

4.3 Feature Model - Level 1

Level 1 is used to represent the processes. Note that only the feature group *Process Specific* is mandatory, but not the process type, so that if no type is selected, the process will have a default operation for a general collaborative process.

Thus, the remaining features are optional: *Decision Stage* enable DM by the collaborators (*DM support* would be required) that can be *Mandatory*, *Binding* for the organization or a *Weighted* decision (required if *Qualified* is selected). Furthermore, several decision types are considered: *Simple* choice, *Multiple* choices, or *Multiple Ordered*.

Regarding the decisions, optionally a *Assessment Stage* can be enabled to evaluate them by collaborators, and consequently being necessary for the general *Assessment* service activation. For effective individual and collective DM, it is necessary the *DM Support* feature activation. *Notification* feature fosters transparency in DM, and can be reinforced with *Debate* and *Meeting* features, above all in deliberative processes.

About process types, according to the e-collaboration process group exposed in Subsection 3.2, the following participatory and collaborative processes are contemplated in the smart governance domain: *Urban Process* and *Urban Project*, *Proposals* (policies, normative or other nature), *Deliberation* about public affairs, *Instrument Making* such as policies, normative or participatory budgets, collaborative *Solution Implementation*, and several types of *Consultations*: surveys, forums, or referendums. Furthermore, through a *Assessment Process* of outcomes or decisions can be evaluated by citizenship, improving accountability.

Regarding mandatory *Process Specific* features, it is required to indicate the *Creation Mode* of the processes: by organization (coordinators), collaborator, smart agent, or event (e.g., a date established in the agenda or the ending of a related process). *Access* mode to processes must be set: open (to anyone interested), restricted or by invitation, by census, or collaborator type/role. Finally, some optional features can be selected by characterizing the participation mode: through delegation (ad hoc in a certain process) or representation (permanent) to another collaborator, and if anonymous participation is established (e.g., for matters protected by data protection laws).

Figure 4 represents the variability of e-collaboration processes through features regarding the collaborative process group described in the previous subsection. To ease readability, *Process Specific* sub-tree has been illustrated in Figure 5.

5 CONFIGURATION TOOL

To assess the usability of the configuration solution, a software tool has been built. In this section, we describe this tool used in an industrial environment. The first approach for the SGPL and its FM has been supported by a configurator (called *InGoverkno*) that allows feature selection from an existing e-governance platform (i.e., Decidim software). Then, the tool configures and deploys an instance of such a platform considering the customization without the need of coding.

The configurator has been designed based on prior general FM, and regarding coverage features. Previously to the configurator implementation, a reduced FM has been made, removing those features that are not present in *Decidim*. This means that any updates to the FM would currently require manual software updates. To this end, both FMs have been specified in Universal Variability Language (UVL) to facilitate their processing and sharing (Benavides et al., 2024). They have been uploaded to UVLHub, a repository of FMs in UVL format (Romero-Organvidez et al., 2024) [4].

The configurator starts from this reduced FM, which is mapped to the specific implementation of the *Decidim* platform, to generate the common artifacts for subsequent configuration and deployment. Through a web user interface (UI) an user may select features and common artifacts. Those features come from the defined FM according to: (1) the e-governance software selected (the Decidim in this first approach), and (2) a subset of processes that this software may manage. Then, the tool would use the values of this form to generate the necessary artifacts and resources and obtain the SPL-derived product, i.e., an instance of the *Decidim* platform. The deployed platform contains the necessary and customized services according to the general FM as described in the previous sections. We note that the configurator also acts at level 4, allowing customizing features for the specific organization such as the organization name or institutional image [5].

Regarding its implementation, the tool has been developed as a web application using the *Ruby* programming language mainly in addition to *JavaScript*. To manage the configuration and deployment of *Decidim* instances, container technology has been used through the *Docker* tool to facilitate compatibility, scalability and efficiency. The source code of the configurator is available in the *GitHub* platform [6].

6 CASE STUDY

To assess the usefulness of our configurability and configurator proposals, the configurator was applied to three municipalities as a case study. To this end, we previously designed a survey to get information about e-governance needs and participative processes demanded. The survey was launched to experts and practitioners in e-governance and related areas such as citizen participation from city councils of different sizes (from the Seville province in Spain). Since the variability in the field of e-governance depends along with other variables, on the size of the city's population, this was the main criterion of choice.

The analysis of the survey responses gave us insight into the e-governance features desired by these municipalities. Then we selected three with different needs and population sizes (one with less than 10,000, another with between 15,000 and 20,000, and another with more than 40,000 inhabitants). This diversity would broaden the variability and make the case study closer to a real environment. So, the smallest municipality demanded citizen (political) proposals, surveys, meetings and debates. The medium-sized one was interested in general proposals, surveys and debates. Lastly, the largest municipality demanded more complex participatory processes such as participatory budgeting and citizen forums. Finally, once the configurator was deployed in a software platform, we applied it to these municipalities, using the features identified through the survey.

6.1 Results

The results supported the survey responses regarding existing variability and confirmed the demand for this type of configuration and automation solutions.

[4] SGPL Datasets are available at http://uvlhub.io/doi/10.5281/zenodo.12697539 and http://uvlhub.io/doi/10.5281/zenodo.15123479

[5] A video of this process can be seen at https://doi.org/10.5281/zenodo.15119490

[6] https://github.com/diverso-lab/ingoverkno

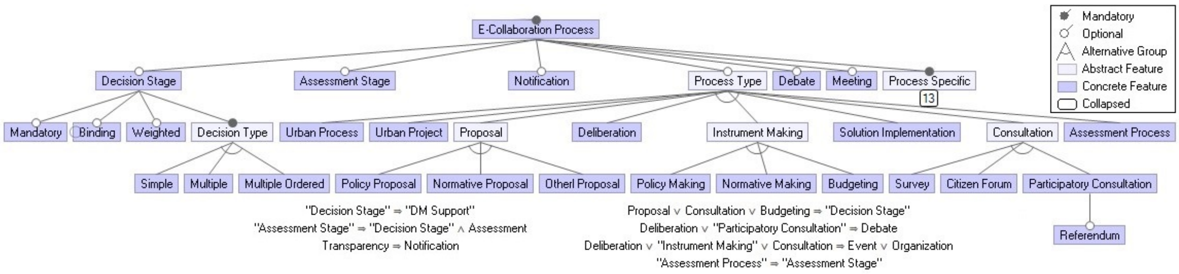

Figure 4: FM for e-collaboration process (level 1).

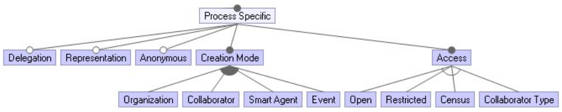

Figure 5: FM for specific features of e-collaboration process (level 1).

The design and development processes of the configurator, revealed that the user interface (UI), the logic of the configuration process, and part of the code, are common across any platform within the implementation domain. This commonality improves usability, ensures a similar configuration process regardless of the platform, and promotes the reuse of code and resources.

In relation to the deployment and configuration process, the main insight drawn has been that operational instances of the e-governance platform tailored to users' needs can be easily obtained in an automated manner. One of the reasons is that the configuration was carried out in the smart governance domain rather than in the application domain, and the concepts are therefore closer to the end user. Thus, the specific details of the *Decidim* platform and its configuration are hidden. This means that users need less technical support.

7 DISCUSSION

Concerning other related proposals, ours focuses on the specific problem of configurability from a general perspective by providing several complementary methods and techniques integrated into the solution: SPLE, multi-level configuration architecture and FM. In addition, we have provided an SGPL-based configuration tool to configure and deploy an instance of the *Decidim* platform from the FM.

The results obtained from the deployment and configuration of *Decidim* in three real and different local councils show that the SGPL, together with the FM, contributes to the general area of e-collaboration and in particular of smart governance. It facilitates the deployment and configuration of these systems, also favoring their reusability, and adaptability with respect to the particular and varying needs of the different stakeholders and organizations.

Nevertheless, due to the complexity and recentness of smart governance, we recognize some challenges and limitations must be taken into account. Thus, although different studies on smart governance identify the same or similar features, there is no total consensus on this and other features could be considered. Furthermore, there are no SPLs or FMs that can be taken as a reference. In addition, a systematic study of the features of the already existing solutions has not been conducted. The vast majority of solutions are limited to e-governance (democratic or participatory) and do not consider smart governance. Therefore we have opted for a domain analysis. Consequently, a complementary work could be application engineering to extract common features and incorporate them into the domain.

8 CONCLUSIONS AND FUTURE WORK

The proposed SGPL addresses a gap in both the literature and industry by offering a general smart governance product line. Its goal is to serve as a guide for practitioners, simplifying the implementation and configuration process within a single software ecosystem. Leveraging reuse and configuration provides significant dynamic variability in services for e-collaboration, particularly in the smart governance domain. This approach is adaptable to the diverse needs of various stakeholders and types of institutions.

To achieve this, the SGPL is built upon appropriate methods and techniques, such as a multi-level configuration architecture. At the first level, it manages the variability of collaborative processes; at the second level, it handles the different governance models. At the third and fourth levels, the overall smart governance platform is configured and tailored to meet the specific needs of the institution utilizing the platform.

To represent the SGPL, the FM provided includes general e-collaboration features and those that are key to smart governance along with their variability, making it easy to obtain a customized line of services for different organizations and stakeholders.

We envision, as a future work, an evolution towards a general configuration and deployment framework to address the automation of the configuration and deployment of the various existing (or newly developed) smart and governance platforms, components and tools. The configurator would choose the most suitable common and specific implementation artifacts to deploy a comprehensive smart governance platform, adapted to the particularities of the institutions and their stakeholders. For this purpose, as a next step, the SGPL-based configurator could be enhanced considering several existing platforms such as *Decidim*, *Consul* or other similar ones. This general configurator would be applied to a wider set of municipalities to validate its usefulness.

Finally, the availability of SGPL-based configurators would allow us to define quantitative performance metrics (e.g., related to time spent on configuration processes, their complexity or accuracy). Those metrics would be used to empirically assess the efficiency and effectiveness of our solution compared to other approaches and proposals for managing configurability. So that we could assess the improvements that SGPL provides along with its methods and techniques.

ACKNOWLEDGEMENTS

This work was supported by the *VII Own Plan* research aid from the University of Seville, FEDER/Ministry of Science, Innovation and Universities/Junta de Andalucía/State Research Agency/CDTI with the following grants: *Data-pl* (PID2022-138486OB-I00), TASOVA PLUS research network (RED2022-134337-T) and AquaIA (GOPG-SE-23-0011)

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