Building Urban Resilience: A Dynamic Process Composition Approach

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Abstract

Urban resilience (also referred to as city resilience) has become a strategic goal of city administrators. Given the diversity of threats and city contexts, managing urban resilience is a complex task that has been conceptualized as a process by the so-called urban resilience frameworks proposed during the last decade. But conceptualization is not enough: an urban resilience building process may last for months, even years, and needs to coordinate many different actors using different tools. Therefore, some type of tool support is required for process control. In this paper, we introduce a proposal for the operationalization of urban resilience processes based on the notion of process family. The notion of process family allows to deal with the natural diversity of urban resilience, and its transformation into a process specification allows the enactment, monitoring and measuring of the process. We have applied our approach to the well-known Smart Mature Resilience framework.

1. Introduction and motivation

Due to rapid population growth and urbanization, cities are becoming more exposed and vulnerable to the effects of a wide spectrum of disasters, ranging from acute shocks such as floods and earthquakes to chronic stresses such as the ones caused by climate change or social dynamics [1]. In such a context, improving cities resilience to expected/unexpected disasters is of utmost importance and requires a holistic approach [2] [3].

Managing urban resilience is a complex task; there are many dimensions of interest (e.g. risk management, urban planning, training and education, etc.), involving different stakeholders, and long-lasting, diverse tasks to perform. Such complexity cannot be managed in an ad-hoc manner, which explains the proliferation of urban resilience frameworks during the last decade. These frameworks aim at supporting resilience managers to assess the levels of resilience, as well as planning future enhancements by means of the application of policies.

The use of Information and Communications Technology (ICT) tools supporting parts of the resilience building process has become usual in most urban resilience frameworks, but a full operationalization of the frameworks is far from being achieved: existing tools give only partial coverage to the theoretical frameworks, making it difficult to provide city administrators full-lifecycle support. Issues like tool interoperability, team coordination, and, most important, support to dynamic action planning, hinder a holistic management of resilience building processes. Only a full digital transformation of urban resilience building processes will provide the level of support required today by resilience managers.

In this paper, we tackle the limitations of current frameworks by using process management as the tool integration technology. Specifically, we provide a solution to define, enact and monitor urban resilience building processes in a holistic way. Our solution is based on the so-called *process family*, an extension of classical business process models to cope with dynamic process (re)configuration. A *process family* represents a group of processes that share a common behavior but can differ from each other in some parts. This definition is similar to that of program families coined by the Software Product Line Engineering community [4].

We illustrate our proposal taking the *Smart Mature Resilience* (SMR, https://smr-project.eu) framework as starting point. SMR defines a resilience building process based on a multidimensional model that uses a maturity level roadmap that cities must follow to reach higher

URI: https://hdl.handle.net/10125/79628
978-0-9981331-5-7

levels of resilience. The transition from one maturity level to the following one is made via the application of a number of policies that cities must implement. These policies are very generic, and cities may implement them in diverse ways depending on their context. There is where variability arises, and our work proposes a technological solution for its management.

The work described here is part of the results of the first year of the INCREMENTAL project, a three-year coordinated research initiative with the partnership of three universities in Spain. Following the Design Science method [5], the project aims at creating synergies between researchers coming from diverse cultures like City Resilience, Prospective and Software Engineering [6]. We present a dynamic process composition approach to improve the operationalization of the SMR framework for urban resilience.

This paper is organized as follows. In Section 2, we provide background on both urban resilience (with focus on variability) and flexible process technology based on *process families*. Then, in Section 3 we introduce our approach and notation for *process family* modelling and in Section 4 we extend the SMR framework with a process layer based in our proposal. Section 5 presents the dynamic configuration of a process using our *process family* approach and an example is used to illustrate the operationalization of SMR. Finally, Section 6 presents our conclusions and future work.

2. Background

We review the state of the art in urban resilience frameworks and family-based flexible processes.

2.1 Principles of urban resilience

During the last decade, a plethora of frameworks to improve urban resiliency have been proposed; many of them aim at addressing climate change effects, while others focus on more specific aspects, such as water lifecycle or natural hazards. We have performed a study of the most recent and relevant urban resilience frameworks, and a summary of our findings is shown in Table 1. In general, urban resilience frameworks are centered on a global, multidimensional view of resilience that includes risk analysis, local economy, transport, urban development, to name a few; others, however, are focused on specific areas such as Water Management or Climate Change.

Every framework defines a resilience building process structured as a sequence of *stages*, *phases*, or *steps*. Although the names of the phases differ from one framework to another, an iterative process pattern can be identified in many of them. First, an assessment stage aims at evaluating the resilience state of the city; next, a set of policies or strategies is selected according with the underlying model; and then, the resilience action plan is executed and the cycle enters in a new iteration until the level of resilience reached is satisfactory.

Besides the iterative resilience building process, a framework includes a multidimensional urban resilience model to assess the city's resilience level. The model is structured as a matrix whose rows represent m dimensions related to different criteria (e.g., community, disaster risk management, local economy, transport, or urban development), and whose columns represent n levels of resilience (e.g. from basic to advanced). The assessment of a city consists of assigning level indicators for all the dimensions by marking the corresponding cells. Each cell of the matrix contains a set of policies or strategies that, when applied, are supposed to move the city to the next level in the corresponding dimension.

Most frameworks have support for some of the stages of their processes. However, full support to the process is still missing, hindering interoperability, and requiring a high degree of human participation [6]. We aim at achieving a full integration of the framework stages and associated tools following a process-based approach. However, classical processes are not enough since the contextualization of the process to each city requires handling process variability.

2.2 Variability in process specifications

The globalization of business, and the need to comply with different regulations, quality standards, and other requirements have made the existence of different variants of the same process be common in modern organizations. However, implementing such variability has proven to be a challenge since it requires a flexible business process specification language that supports modelling the required process variants, and whose runtime semantics copes with all the possible process execution scenarios [18].

Traditional process modeling languages such as BPMN [19] cannot represent flexible processes properly since they were not designed to specify variability. Therefore, the specification of a flexible process using such languages is made *ad hoc* by including all variants in a single model and driving the control flow by means of conditional gateways. This results in overly complex models, including redundant tasks, as well as numerous process variables that are inserted artificially in the specification to support flexibility. Flexible processes have been subject of extensive research in the last decades (see e.g. [18, 20, 21]). Most proposals are extensions of languages like BPMN, but also declarative languages have been proposed; however, the latter have been criticized for their lack of intuitiveness [22]. We

Table 1. Summary of the resilience building process

Framework Name	*Org./Author*	*Phases*	*Areas*	*Ref.*	*Year*
IAP	The Rockefeller Foundation in collaboration with ICLEI	• Phase 1: Engagement • Phase 2: Climate research and impacts assessment • Phase 3: Vulnerabilities assessment • Phase 4: City resilience strategy • Phase 5: Implementation • Phase 6: Monitoring and Review	Urban Climate Change Resilience	[7]	2014
OECD Resilience Systems Analysis	OECD together with other members of the Experts Group on Resilience	• Step 1: Governance and scope • Step 2: Pre-analysis and briefing pack • Step 3: The workshop • Step 4: Using the roadmap to boost resilience	Risk and Build a Roadmap to Resilience	[8]	2014
The CityStrength Diagnostic Tool	World Bank The Global Facility for Disaster Reduction and Recovery (GFDRR)	• Stage 1: Pre-Diagnostic Review • Stage 2: Launch Workshop • Stage 3: Interviews and Field Visits • Stage 4: Prioritization • Stage 5: Discussion & Next Steps	Different Areas and Builds a Roadmap to Resilience	[9]	2015
ERMG	Smart Mature Resilience (SMR) closely together with research partners	• Baseline review • Risk Awareness • Resilience Strategy • Implementation & Monitoring • Evaluation & Reporting	Multi-disciplinary for more Resilient Cities	[10]	2018
RESIN	Eleanor Chapman (ICLEI – Local Governments for Sustainability)	• Phase 1: Assess climate risk • Phase 2: Develop adaptation approaches • Phase 3: Prioritise adaptation options • Phase 4: Develop implementation plan	Climate Resilient Cities and Infrastructures	[11]	2018
CityRAP	UN-Habitat and DiMSUR	• Phase 1: Understanding urban • Phase 2: Resilience data collection and organisation • Phase 3: Data analysis and prioritisation • Phase 4: Development of the city resilience framework for action	Urban Planning, Climate Change, and other Stresses	[12]	2018
EVCA	International Federation of Red Cross and Red Crescent Societies (IFRC)	• Stage 1: Engaging and connecting • Stage 2: Understanding risk • Stage 3: Taking action for resilience • Stage 4: Learning explains	The Roadmap to Community Resilience	[13]	2019
IAdapt	ICLEI, South Asia, in partnership with Athena Infonomics LLC Pvt. Ltd., IWMI and IITM	• Phase 1: Engagement Phase • Phase 2: Baseline Assessment • Phase 3: Vulnerability Assessment • Phase 4: Solution Assessment • Phase 5: Development of Catchment Management Plan (CMP)	Climate Change Adaptation in Water Resource planning	[14]	2019
MCR2030	UNISDR and its partners	• Stage A: Cities know better, • Stage B: Cities plan better • Stage C: Cities implement better	Reduce Risk and Improve Resilience	[15]	2020
CURE	CURE Members Chrysoulakis et al., 2020	• Cases Studies • Urban Planning Community • Workshops	The Multi-dimensionality of Urban Resilience	[16]	2020
ReBuS	Council of Europe Institute of International Sociology of Gorizia (ISIG)	• Phase 1: Setting up a community resilience task • Phase 2: Assessing community resilience • Phase 3: Setting objectives for community resilience • Phase 4: Action planning	Building Community Resilience	[17]	2021

have based our work in two non-declarative proposals, namely PESOA and Provop. While the former promotes modelling variability in different application environments as a collection of related *process model variants* belonging to the same *process family, the* latter borrows the UML 2.0 mechanism of stereotypes to define a variant-rich process model as a classical process model extended with stereotype annotations to accommodate variability. A summary of both approaches follows.

2.2.1 The Provop approach

The Provop framework is a structural configuration approach to variability where *process families*, composed of process *variants*, can be created from a so-called *base process model* by applying a predefined set of structural changes both by restriction and extension [23]. These changes, called *adaptations*, may consist of inserting, modifying, or deleting activities or process fragments at some points of the reference process model known as *adjustment points*. Figure 1.a shows a sequential base process model composed of five activities named A to E. Notice that two black diamonds, representing the adjustment points, have been drawn between activities B and C. They mark the part of the process where changes may be made. Figure 1.c shows three variants of the base process, namely S1, S2 and S3 obtained by applying the adaptations shown at Figure 1.b.

Unlike ad hoc variability modelling, in Provop the base process model does not include all variations; rather, variations are applied *on demand* and dynamically by means of structural changes that may be driven by some context. Once the adaptations have been performed, the resulting variants are pure BPMN models, so they can be executed in a BPMN process engine. This approach provides a very simple, modular and expressive mechanism for variability modeling. The language admits variation points with respect to activities, tasks or subprocesses.

2.2.2. The PESOA variability approach

PESOA is a technique for variability modelling that borrows the UML 2.0 mechanism of stereotypes [24]. According to PESOA, a *variant-rich* process model is a process model extended with stereotype annotations to accommodate variability (see Figure 2). Unlike Provop only variability by extension is supported. The elements of a process model where variability can occur are marked as variation points with the <<*VarPoint*>> stereotype. A variation point represents an abstract action that needs to be realized with a concrete instance or variant (<<*Variant*>>) among a set of ones. If variants are exclusive, i.e., only one variant can be assigned to a given variation point, the <<*Abstract*>> stereotype is used instead of <<*VarPoint*>>. When

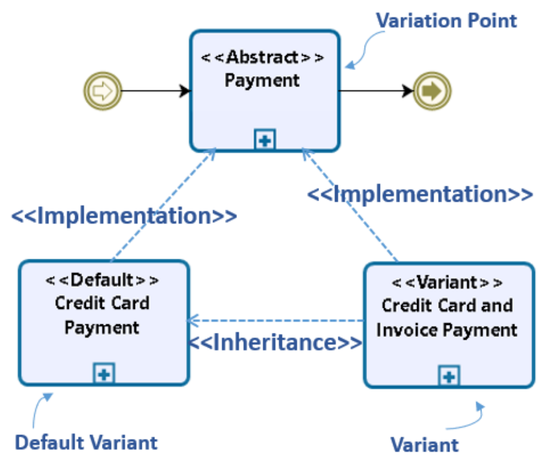


Figure 2. PESOA's variability modeling

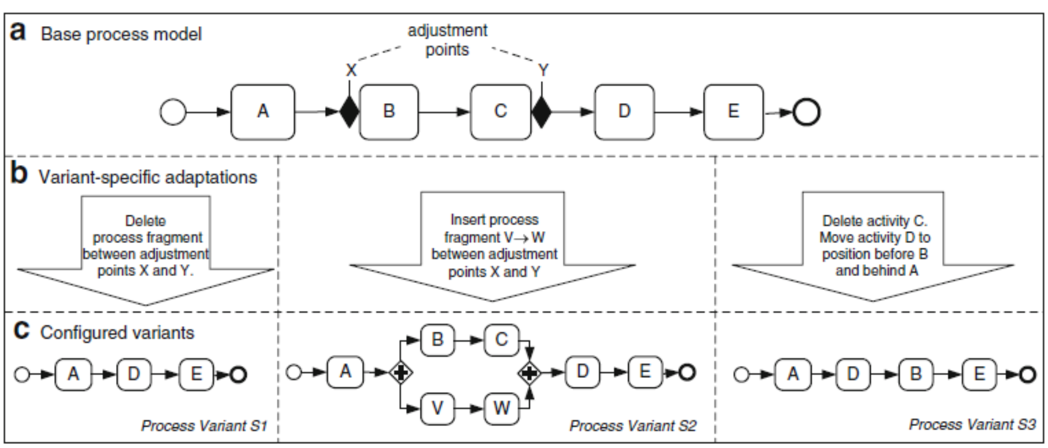


Figure 1. Provop approach for variant modelling (taken from [23])

there are several implementations and one can be considered the default option, it is tagged as <<*Default*>>. Figure 2 shows an example of variation point. The subprocess "Payment" is labelled with the <<*Abstract*>> stereotype to indicate that it admits different implementations. There are two implementations: "Credit Card Payment" and "Credit Card and Invoice Payment," with the former marked as the default implementation. <<*Inheritance*>> stereotype modifies an existing subprocess by adding activities. Other stereotypes can be found in [24].

3. Variability in urban resilience models

Despite the small number of stages included in urban resilience building processes (typically between 4 and 6, as shown in Table 1), they are particularly complex due to several reasons. First, the stages are far from simple, include many activities with many actors involved, and may last for days, months or even years. Therefore, coordinating and monitoring the enactment of the stages is of capital importance. Second, applying the resilience model is not straightforward; rather, it is highly dependent of the context of the city under evaluation and, as such, requires flexible approaches. Flexibility must be understood in terms of *variability*.

To illustrate this, let's imagine that at some point of the resilience process, the policy *"Adopt solutions to prevent climate change effects"* must be applied. It is foreseeable that the application of the policy by a city in a mountain area will be quite different to those of a city in a coastal zone since the threats are different, and hence they require to apply distinct measures. Summarizing, we can say that policies in the models are *abstract* and can have more than one implementation or *instances* depending on cities' contexts. Therefore, we refer to this diversity as *abstract-to-instance* variability.

There is yet another type of variability in resilience models that relates with the selection of the policies to be applied at each iteration. As mentioned earlier, every cell in the matrix contains a set of policies that are supposed to move cities towards upper levels of resilience in the corresponding dimensions. Apart from abstract, some policies require efforts (human, budgetary, or of any other type) that a given city may not be able to assume at some point, so their administrators might decide to postpone their application until resources are available. This means that two similar cities, in the same resilience state, can define different activities for their next iteration, adding complexity to the management of the processes. We will refer to this variety as *policy-selection* variability.

Looking for a notation able to represent both types of variability, we decided to take a hybrid approach. We use PESOA's notation to model *abstract-to-instance* variability, and Provop's notation for the policy-selection, as we show below.

4. A process layer on top of SMR

The *Smart Mature Resilience* (SMR) framework for city resilience is the result of a multidisciplinary research project funded by the European Union Horizon 2020 program. The European Resilience Management Guideline (ERMG) is the name of SMR's resilience building roadmap, which guides cities in a five-step iterative process (see Table 1, ERMG row). Each step includes a set of activities to perform with the help of one or more tools [10].

The first step to incorporate a process layer on the top of SMR consists of modelling the ERMG as a process specification. Each operational step of ERMG is represented by a subprocess in a BPMN sequential control flow, as Figure 3 shows. When the last subprocess is completed, there is a decision to be made

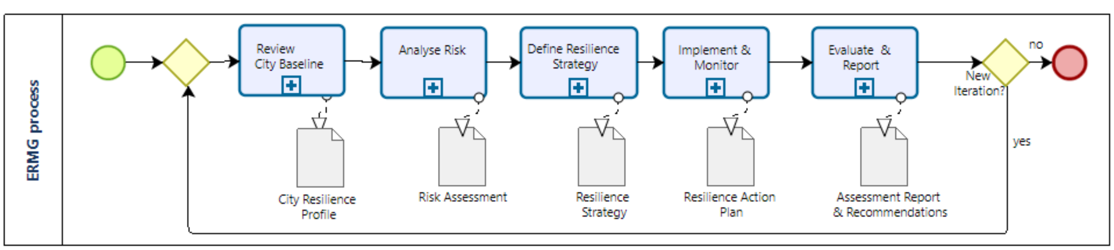


Figure 3. SMR's European Resilience Management Guideline process

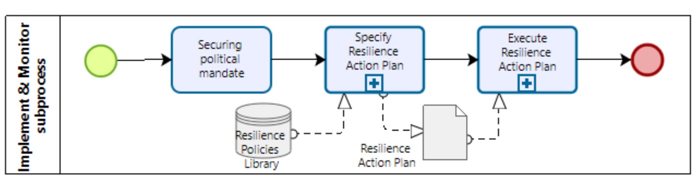


Figure 4. Expansion of the Implement & Monitor subprocess

by the city's resilience manager (who is part of the municipal staff and manages the decisions of the municipal government or city administrators) and represented by the XOR gateway that can lead either to a new iteration (aiming at further improving the level of city resilience) or to the end of the resilience building process. There is also a data flow between subprocesses, but in Figure 3 only the main artifacts generated in each subprocess are shown.

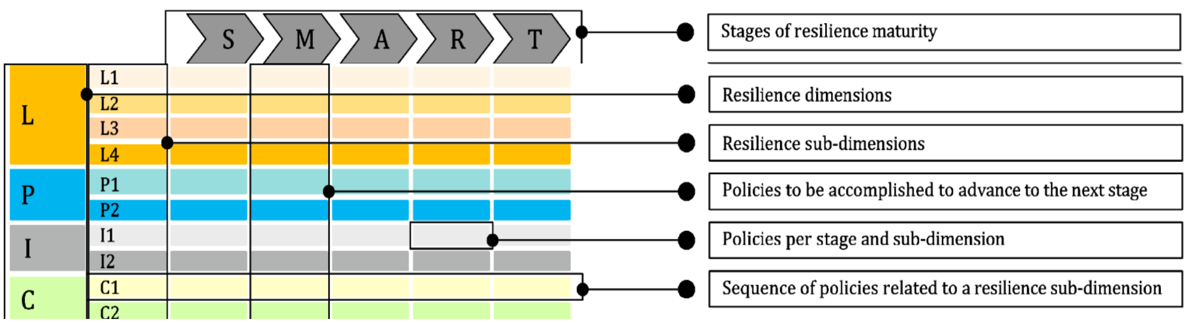
Space limitations prevent us to show a full description of the process, so we focus on the specification of the *Implement & Monitor* subprocess. Its goal is to generate and execute the resilience action plan for the current iteration of the resilience process. As Figure 4 shows, it is composed of one manual activity and two other subprocesses. Specifically, the *Specify Resilience Action Plan* subprocess generates a resilience action plan using a variability-aware process modelling approach and the *Resilience Maturity Model* (RMM) [25]), a strategic tool that provides a roadmap for improving a city's resilience level similar to other well-known maturity models, such as CMMI (Capability Maturity Model Integration) [26]. The generated resilience action plan is executed as the last activity of this ERMG step.

4.1 Modelling RMM using *process families*

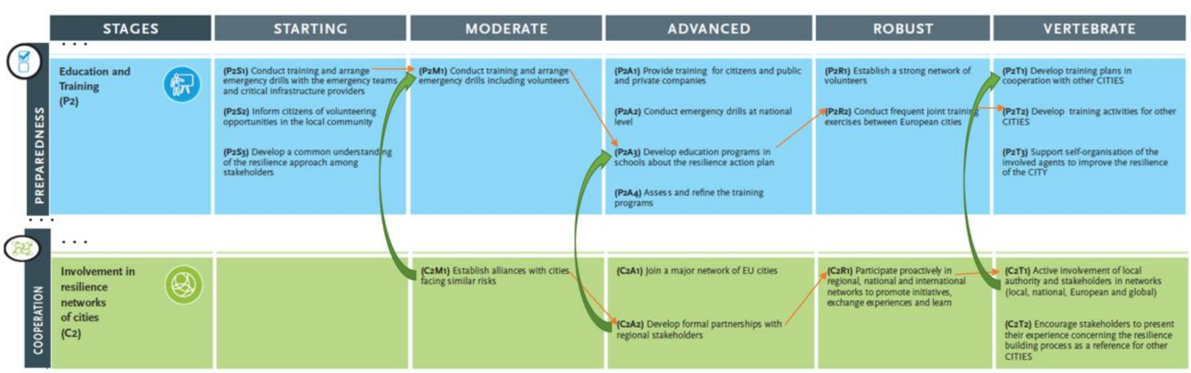
The RMM is an instance of the model template shown in Figure 5.a. It is represented as a matrix whose rows are associated with general dimensions (namely, *Leadership and Governance* (L), *Preparedness* (P), *Infrastructure and Resources* (I) and *Cooperation* (C)) that are refined into more specific subdimensions. The matrix columns represent the five maturity stages (from lowest to highest: ***S**tarting*, ***M**oderate*, ***A**dvanced*, ***R**obust*, and *ver**T**ebrate*) where cities can be found in each subdimension. For each cell in the matrix, a fixed and closed set of policies are defined. Figure 5.b shows the policies defined in subdimension P2 (*Education and Training*) as well as those defined in subdimension C1 (*Involvement in resilience networks of cities*).

The resilience building process of a city starts in the lowest resilience level and aims at progressing in the stage hierarchy. The city's resilience maturity stage depends on the policies it successfully implements. The ultimate goal is to lead the city to levels as high as possible in all the subdimensions of the model. In this path, two fundamental issues must be addressed:

Dependence relationships. Policies are not independent from each other; rather, there are some dependencies that must be considered when defining a resilience action plan. On one hand, to move from one



a. Explanation of the RMM



b Excerpt from the RMM matrix

Figure 5. SMR's Resilience Maturity Model (RMM) (taken from [25]).

stage to the next one in a particular subdimension, all policies defined for that stage must be implemented. On the other hand, the activation of some policies in a dimension may depend on the completion of policies in other dimensions. We refer to these constraints as horizontal and vertical dependencies, respectively. They are represented in Figure 5.b respectively as directed lines between policies and they are useful for a continuous or staged representation of RMM, similar to other maturity models.

Variability. Managing the RMM requires the two types of variability mentioned in Section 3. On one hand, policies in the RMM are described at a very high level (e.g. "*Establish a strong network of volunteers*"), and can be implemented in many different ways by different cities, yielding to an *abstract-to-instance* variability scenario. On the other hand, in a particular iteration of the process, a city can decide not to implement all the policies of a matrix cell (e.g. due to budgetary constraints, lack of staff, etc.), so the policy is applied only partially; this is an example of *policy-selection* variability. Therefore, a variability-aware process modelling approach must be used transforming ERMG into a fully executable process.

4.1.1 Combining *abstract-to-instance* and *policy-selection* variability styles. We consider each cell in the RMM matrix as a *process family*. For instance, at the crossing between the *Moderate* stage and the subdimensions *Preparedness* (P2) and *Cooperation* (C2), there are respectively the policies "*Conduct training and arrange emergency drills*" (P2M1) and "*Establish alliances with cities facing similar risks*" (C2M1). Notice that there is a vertical dependency from C2M1 to P2M1.

Both cells are represented as *process families* in our approach (see Figure 6) combining the PESOA notation (modelling the *abstract-to-instance* variability) and the Provop notation (*policy-selection* variability). Additionally, the new connector (the double-bordered or thick hexagon) is used to represent respectively the origin and target of the vertical dependency between policies. Horizontal dependencies are represented by standard BPMN connectors.

The set of *process families* representing RMM is modelled and stored in a repository called *Resilience Policies Library* for (re)use them in the building of the resilience action plan (see Figure 7 expanding the abstract "*Provide training*" police used to illustrate the dynamic configuration).

5. Dynamic configuration of the ERMG process

Our operationalization of the ERMG allows cities to implement, enact and monitor their resilience action plan. But the process family-based specification must be converted to an executable form. In this section, we describe the steps of the transformation by means of an example of fictitious city.

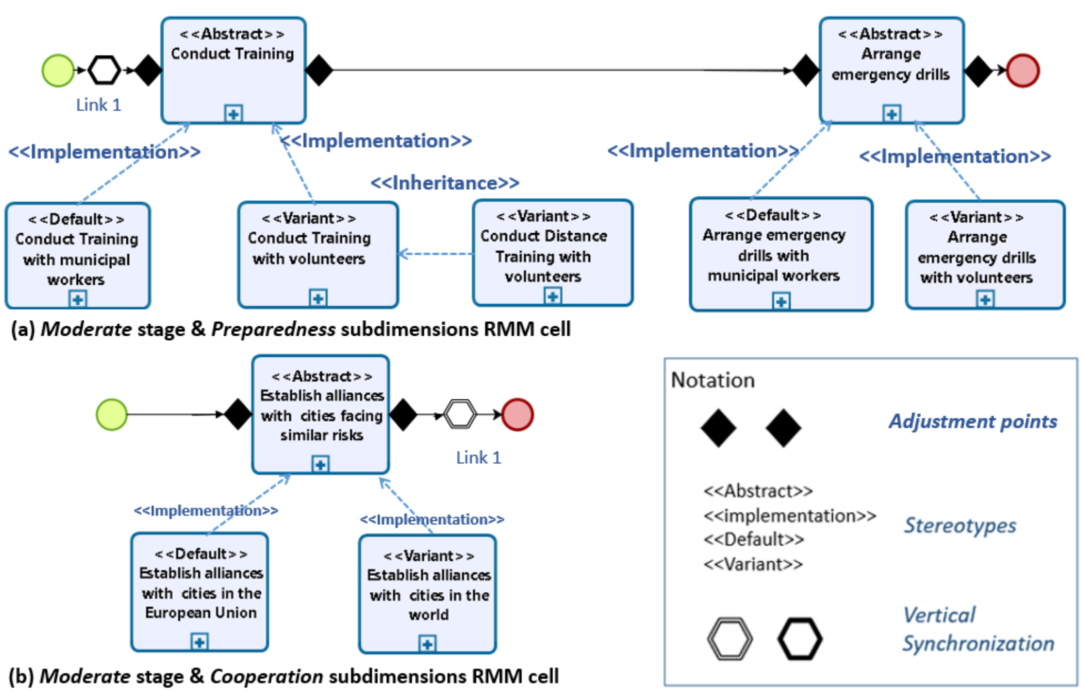


Figure 6. Policies in RMM as *process families*

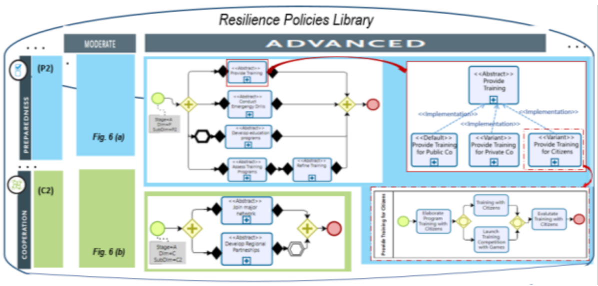


Figure 7. Resilience Policies Library

Step 0. City evaluation. The resilience building process starts by calculating the current resilience status of the city using RMM's criteria (not mentioned on this paper, but available at [25]). As a result of the evaluation, the position of the city within the RMM matrix is determined. In the example used the city has completed thus far the ***M****oderate* stage.

Step 1. Search and retrieval. In this step, the resilience planner decides which aspects of the city's resilience to improve in the next iteration. In other words, what (sub)dimensions will be part of the iteration. The decision is used to build the search string and query the *Resilience Policies Library* to retrieve the *process families* that represent the policies that the city should/could apply in the next iteration. In our example, the city resilience team decides to focus on preparedness and cooperation to improve the city resilience and reach the ***A****dvanced* stage. Specifically, the subdimension P2 (*Education and Training*) and subdimension C2 (Involvement in resilience networks of cities) of RMM are chosen. Figure 8(a) shows the *process families* retrieved from the *Resilience Policies Library* (the *abstract-to instance* variability is not shown for clarity of the Figure).

Step 2. Process Composition. The *process families* retrieved from the *Resilience Policies Library* must be merged into a global process according to the following rules: a) the *process families* to be composed become parallel paths of the global process (the AND-gateway of BPMN is used); b) the vertical dependencies (if any) between policies, represented by the new hexagon-shaped connectors, are converted to an AND-join. The new global process is a *process family* itself and it represents the family of resilience action plans for the city. Figure 8(b) shows the global process family obtained by composing the two *process families*.

Step 3. Configuration. The resilience planner configures a specific instance of the *process family* that will represent the resilience action plan to apply. This means removing both *abstract-to-instance* and *policy-selection* variability. They can be managed in any order. On the one hand, managing the *policy-selection* variability implies that the resilience planner derives a specific variant using the variant-specific adaptations (in this case, delete or not the actions between the adjustment points). On the other hand, solving the *abstract-to-instance* variability requires that the resilience planner chooses one of the implementations of the abstract policy.

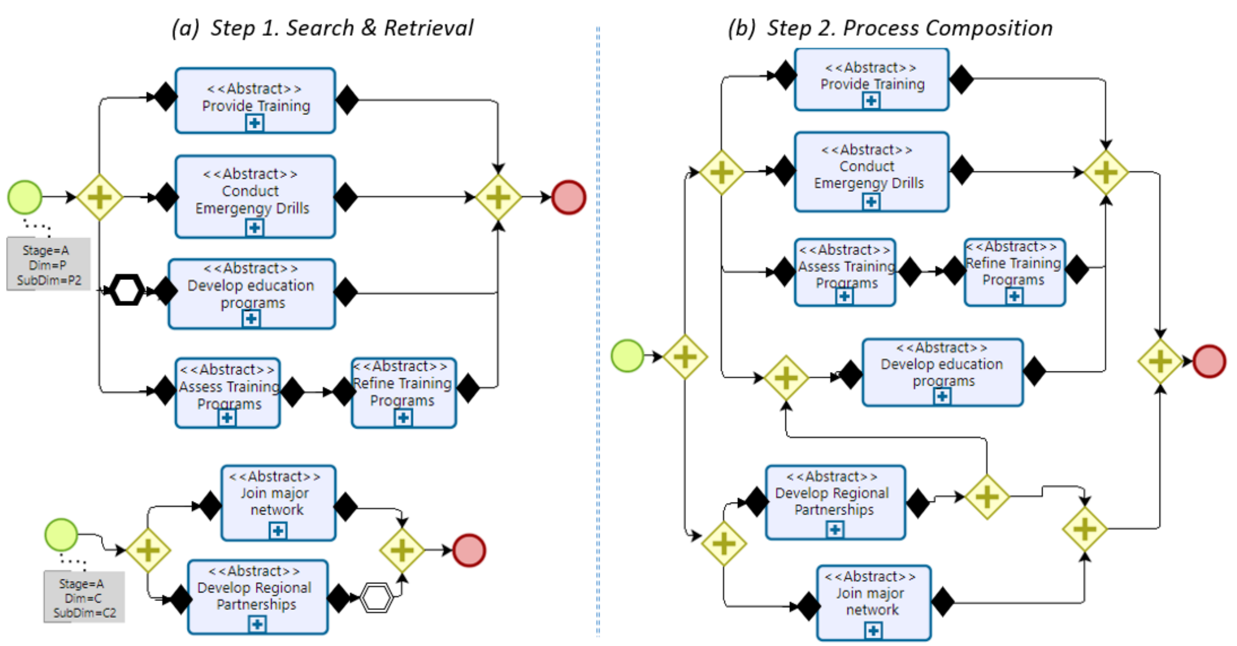


Figure 8. Process composition to build the Resilience Action Plan

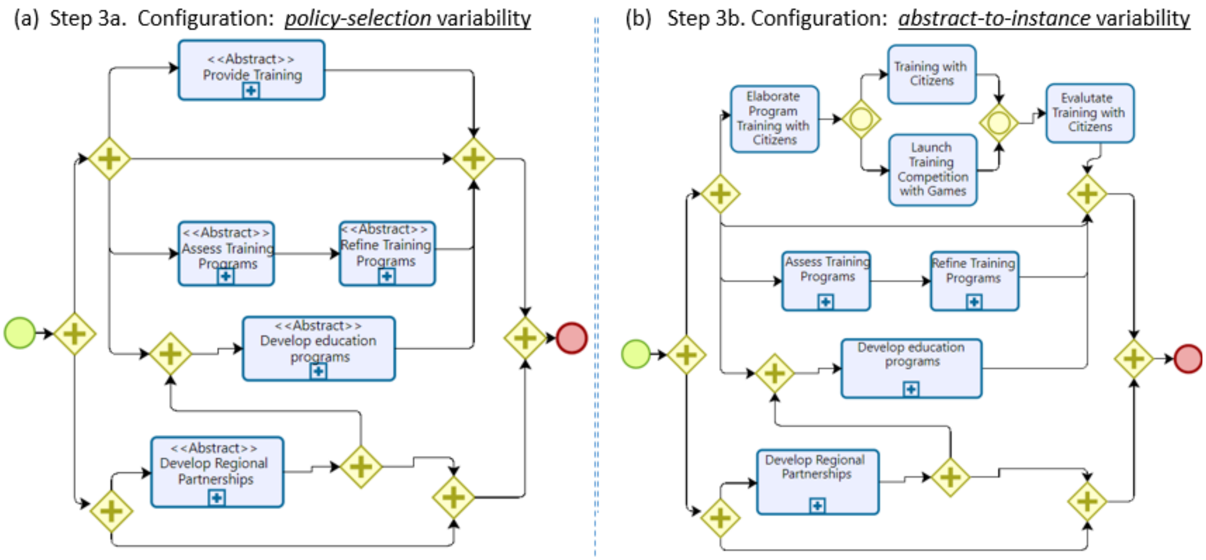


Figure 9. Two-step variability configuration

In the example, if the resilience planner decides to improve training but not to conduct drills to reduce costs, these drills are postponed to future iterations of the resilience process. To apply this decision, the *Conduct Emergency Drills* (P2A2) and *Join major network* (C2A1) policies are marked for deletion (see Figure 9(a). The configuration obtained is checked according the variability dependences in RMM and Provop model constraints. Next, for each variant point, an implementation of the abstract element is selected (see Figure 9(b)).

After the configuration, all the variability points disappear, and we obtain a specific resilience action plan; at this point, the *Specify Resilience Action Plan* subprocess is finished. The output is a BPMN model that can be executed directly by a process engine (e.g. CAMUNDA (http://camunda.com)) when the *Execute Resilience Action Plan* subprocess starts.

Those policies not applied in an iteration, due to *policy-selection* variability management, must be available for selection in the next iteration of the ERMG process. For this purpose, all the iterations of the ERMG for a particular city must be stored as process state (policies completed/policies not started).

6. Conclusions and further work

The early 2020s mark the beginning of the Digital Transformation age, in which ICT adoption has changed traditional practices in many domains, with impact on Digital Government. While the transformation pace has been high in areas like public participation, this was not the case, however, of urban resilience frameworks, that remain at a conceptual and strategic level, making use of tools only in some parts of their resilience building processes.

The complexity of the domain, however, requires a holistic approach to cope with the multidimensional nature of resilience. Dealing with long-lasting processes, involving different stakeholders, and managing a manifold of information artifacts makes it necessary to have integral tool support, currently not available. Current frameworks remain at a conceptual level and are unable to provide a full operationalization of the resilience building process.

In this paper, we have shown how process technology can play a crucial role in the digital transformation of urban resilience frameworks by providing both conceptual and operational support to the resilience building processes. Specifically, we have used the BPMN notation to model the overall process, plus the concept of process family to model the variability intrinsic to the city resilience frameworks.

We have applied our ideas to the SMR framework, in particular in the digital transformation of its resilience maturity model. We have defined the resilience building policies as process families so that, on one hand, a given policy can be implemented in different ways according to the context of a city, and, on the other hand, we open to door to partial implementations of policies according to the convenience or capabilities of the city.

At the present state, the selection of process variants is made by cities' resilience administrators. We are working on the definition of a number of indicators that allow more automation in the selection of instances, creating a recommendation utility to be added to the framework. As for future work, we plan to generate a multi-framework modelling tool allowing the semantic interoperability of several city resilience frameworks; such tool would enable the definition and enactment of resilience processes based on multiple frameworks, covering this way as many dimensions as possible.

7. Acknowledgements

This work is funded by Spain's *Ministerio de Ciencia e Innovación* under grant MIGRATE (PID2019-105414RB-C31). We also thank our anonymous reviewers, whose constructive comments helped to improve the quality of the paper.

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