SMART MATURE RESILIENCE, SYSTEM DYNAMICS BASED INTERACTIVE LEARNING ENVIRONMENT: A BETA VERSION

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ABSTRACT
Natural and man-made disasters are becoming more frequent – unfortunately in most cases inevitably. By applying certain set of policies and guidelines, a city could resist, absorb, adapt to and recover from acute shocks and chronic stresses to keep critical services functioning, i.e. be resilient. In 2016, the Smart Mature Resilience, a Horizon-2020 EU project, defined the Resilience Maturity Model to make cities more resilient. In addition, the project is implementing a System Dynamics simulation model to be used by cities in planning and training for resilience. The System Dynamics model is encapsulated in a web-based Interactive Learning Environment, an easy to use Graphical User Interface (GUI). The beta version of the Interactive Learning Environment was tested by the Smart Mature Resilience project partner cities' representatives and experts in the SMART MATURE RESILIENCE second review workshop in March 2017. The participants formed in groups were supported by moderators; meanwhile recorders took notes and suggestions. This paper introduces the Interactive Learning Environment and its functionalities, in addition to information reported by the recorders for further enhancements.
Keywords: city resilience, disaster resilience, interactive learning environment, resilience maturity model, resilient tool, smart mature resilience project, system dynamics

1 INTRODUCTION

'A disaster (catastrophe) can be interpreted as an event that causes great destruction/damage and human suffering' [1]. Man-made as well as natural disasters are steadily increasing over time [2]. Their effect is enormous as well, in 2014, the United Nations reported that disasters in some way or the other have affected 4.4 billion persons, killed 1.3 million lives and caused economic losses of USD 2 trillion during the two decades prior to the report [3], and according to Swiss Re Sigma Report in 2016, all over the world, 155 man-made events and 198 natural catastrophes were recorded during 2015 causing as twice as the number of deaths than in 2014 [4]. According to the same report, disasters in 2015 caused economic losses of USD 92 billion.

While most natural disasters are mostly inevitable, their physical impact and consequences can be diminished through prevention and mitigation measures [5]. In the aftermath of these disasters, the need to enhance the ability to manage and assess the cities' resilience has gained increasing importance. The United Nations International Strategy for Disaster Reduction (UNISDR) defines resilience as 'the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure' [6].

In Europe, there is a political interest and pressure to prepare cities to be resilient. As an example, in 2013, the European Commission adopted the European Union Adaptation strategies focusing on cities resilience to climate change [7]. Yet, despite this pressure and the importance of improving cities' resilience, there are currently limited examples of the

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sequential steps that cities should follow in developing resilience [8]. Furthermore, not all cities have the same resilience level, and there is a lack of guidance on which policies should be implemented as a function of the current situation of a city [9]. In addition, there is insufficient understanding of how the city stakeholders should work and collaborate to develop the city's resilience [10]. Smart Mature Resilience is a European Horizon 2020 project started in 2015, and aims at preparing and validating a Resilience Management Guideline through defined set of tools and policies that help city stakeholders enhancing the cities' resilience, and provide the cities with a robust shield against man-made and natural hazards, enabling societies to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner [11]. The project will be described further in Section 3.

A selected set of these resilience policies were introduced via a mathematical model built using System Dynamics methodology. System Dynamics is a computer-aided modelling approach to capture a complex system and interactions among system's components that will generate the behaviour of the system over time. In the Smart Mature Resilience project, this System Dynamics tool is used to allow city stakeholders simulating different resilience policy options and learn about the consequences of their decisions on the maturity of the city resilience.

The System Dynamics model was encapsulated in an user-friendly Graphical User Interface (GUI) called System Dynamics based Interactive Learning Environment to facilitate better understanding of the Resilience Maturity Model, which is another tool of the project, and accordingly be used as training tool for decision makers and crisis managers to make them well prepared for future crisis. This Interactive Learning Environment is intended as a training tool for city stakeholders. The beta version of the Interactive Learning Environment was tested among approximately 30 city stakeholders of the Smart Mature Resilience project partners in combination with focus group discussions in project workshop done in Donostia/San Sebastian, Spain, March 2017. The evaluation results of the pilot testing are reported in this paper, covering the impression of the Interactive Learning Environment's GUI and the elements included in the model. The objective of this paper is to present this beta version of the Interactive Learning Environment as one of Smart Mature Resilience project tools, and discuss and analyse the results of the pilot testing of this tool during the workshop with the Smart Mature Resilience project stakeholders, in terms of these stakeholders' opinions and perceptions about the Interactive Learning Environment.

This paper is organised as follows: the next section introduces the concept of Interactive Learning Environment. Section 3 familiarises the reader with the Smart Mature Resilience project, which is followed by a brief description of the Smart Mature Resilience System Dynamics model, and the Interactive Learning Environment's GUI and its functionalities. Section 5 describes the workshop held in Donostia and presents the results of this workshop, followed by section 6 analysing these results. Section 7 makes an overall conclusion of the paper.

2 STATE OF ART: INTERACTIVE LEARNING ENVIRONMENT

Generally, an Interactive Learning Environment is defined as a 'software for educational purposes, for supporting the process of learning, where the focus is on learning through the interaction with the computer (human-computer interactivity)' [12]. Interactive Learning Environment is referred to as management flight-simulator, microworld, business simulator, or management simulator by various publications [13, 14]. However, in this paper, we do not differentiate between these terms.

A mental model, in general, could be defined as 'a construct of cognitive psychology. Mental models are internal representations of conceptual and causal interrelations among elements that people use to understand phenomena' [15].

Interactive Learning Environments are developed either for educational or research and validation purposes [16]. For educational purposes, Interactive Learning Environments wish to change the mental models of their users, while for research and validation purposes Interactive Learning Environments aim at identifying their users' mental models.

Interactive Learning Environments have been demanded lately not only because society has evolved into a more technological society [17–19], but also, there has been an evolution in the teaching field. The education has evolved from teacher-centred to learner-centred, from listening model to doing model and from memory learning to search and information use learning [17]. Furthermore, Interactive Learning Environment has the ability to engage user producing a high positive impact on them [17, 18]. For example in Ref. [17], an Interactive Learning Environment is presented with the aim of improving users intercultural awareness, knowledge and communicative competences at the university level. However, in Ref. [20] an Interactive Learning Environment called WeBlog is developed in order to demonstrate the benefits of implementing lean concepts in a company. In both cases users' attention and motivation were high, and the theoretical concepts taught by the Interactive Learning Environments were successfully transferred.

Multiple studies have shown that Interactive Learning Environments can be effective when applying to education [17, 18, 21] providing high benefits in comparison to conventional methods [22]. Ke pointed to content, context and the achieved competences as key factors for success [23]. Sitzman added the necessity of Interactive Learning Environments to be designed as an active learning tool and the importance of having Interactive Learning Environment combined with other tools to ensure its success [24]. Finally, Hamari stated that simulating real world tasks and giving instant feedback help to develop successful Interactive Learning Environments [25]. Related to what these three authors say, Wouters *et al*. [22] described three main aspects to take into account in order to assure effectiveness and success of Interactive Learning Environments: (1) changing the cognitive process (via active learning), (2) affecting motivation (simulating real world tasks for example), and (3) provide the sensation of having learnt (via instant feedback). As a final point in this section, Interactive Learning Environments have proven to be successful educational tools in the context of public policies, both on the national and city levels [26, 27].

3 SMART MATURE RESILIENCE PROJECT

Smart Mature Resilience will deliver a validated Resilience Management Guideline which covers different problem areas such as security sectors in Critical Infrastructures, as well as climate change and social dynamics. The main objective of the project is to provide through the Resilience Management Guideline a robust shield against man-made and natural hazards, enabling society to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner. The Resilience Management Guideline is based on five tools: The Resilience Maturity Model, the Systemic Risk Assessment Questionnaire, the Engagement tool, the System Dynamics model and the Resilience Building Policies.

In this paper the first version of the System Dynamics model is presented and discussed. The System Dynamics model is encapsulated in an Interactive Learning Environment and based on the policy implementation of each Resilience Maturity Model stage developed on the Smart Mature Resilience project. The System Dynamics model aims to build a tool that facilitates decision makers and crisis managers to better understand the Resilience Maturity Model and therefore train them to be well prepared for future crisis.

The Resilience Maturity Model engages a growing number of stakeholders and multi-level governance in order for cities to become more resilient, defining five maturity stages: *Starting*, *Moderate*, *Advanced*, *Robust*, and *verTebrate* (SMART). Each of these maturity stages includes a description of the objectives of each stage, the agents involved in each maturity stage and a set of resilience building policies to implement in order to reach the objective of each stage and move forward. Therefore, policies are classified depending on their maturity stage and their resilience dimension (see Figure 1). In addition to the five maturity stages, the Resilience Maturity Model is structured in four resilience dimensions: Leadership and Governance, Preparedness, Infrastructure and Robustness and Cooperation. These four dimensions are also divided in sub-dimensions having a total of 10. The presented policies are inter-related between each other with predecessor relationships. Therefore, policy implementation order will determine the efficiency of how the maturity stages are obtained as before applying some policies others should have been implemented before.

4 SMART MATURE RESILIENCE SYSTEM DYNAMICS MODEL

The System Dynamics based Interactive Learning Environment introduced in this paper includes a pilot version as it contains 19 out of the 98 policies the Resilience Maturity Model has. The aim of the Interactive Learning Environment is to provide a tool that enables decision makers and crisis managers to train themselves and better understand the Resilience Maturity Model in order to achieve higher resilience levels for their cities and understand the path toward building resilience. The System Dynamics model and Interactive

			MATURITY STAGES				
			STARTING	MODERATE	ADVANCED	ROBUST	VERTEBRATE
RESILIENCE DIMENSIONS	Leadership & Governance	L1	Policy of starting stage L dimension	...	...	...	...
		L2	...	...	...	...	...
		L3	...	...	...	...	...
		L4	...	...	...	...	...
	Preparedness	P1	...	...	...	...	...
		P2	...	...	...	...	...
	Infrastructures	I1	...	...	...	...	...
		I2	...	...	...	...	...
	Cooperation	C1	...	...	...	...	...
		C2	...	...	...	...	Policy of vertebrate stage C dimension

Figure 1: Resilience Maturity Model structure.

Learning Environment were built with the intention of serving users for decision making and mental model enhancement. To develop this Interactive Learning Environment, we were faced with two alternatives; desktop/mobile application and cloud/web-based. Several features including cost, agility, and scalability were provided solely by the cloud/web-based solution [28]. Moreover, it provides the possibility to be accessed anywhere, without the need for particular software installation [28–31]. Accordingly, we went for the cloud/web-based solution.

Several tools could provide the cloud/web-based solution like *Forio Online Simulations*, *iMODELER*, *Insight Maker*, *Sysdea*, *isee Exchange*, and *BROADVIEW*. InsightMaker is distinguished by being totally client-side without any need for a server other than a web-server/web-hotel, in addition to being an open-source tool. Going for the InsightMaker solution saves the cost of having a server dedicated for model solution every time a user wants to simulate her/his scenario, and provides the freedom to distribute the solution among several cities without any additional cost. Furthermore, the InsightMaker solution is integrated, as there is no need for an additional System Dynamics model building software. The following subsection introduces the Smart Mature Resilience System Dynamics Model in a nutshell, followed by a subsection that describes the Smart Mature Resilience Interactive Learning Environment more detailed.

4.1 Smart Mature Resilience System Dynamics Model

The System Dynamics model represents the structure of the Resilience Maturity Model and determines the relationships between policies. As explained in Section 3, the Resilience Maturity Model is composed of five different maturity stages and four resilience dimensions, which are divided into different sub-dimensions. As a consequence of this structure, two types of relationships have been defined: linear relationships and transversal relationships (see Figure 2).

Linear relationships refer to temporal relationships that exist among the different maturity stages. This means that policies in the lower maturity stages should be developed in order to implement the policies in the higher maturity stages. For example, within each sub-dimension, policies in the 'Starting' stage should be developed in order to implement the policies in the 'Moderate' stage, and similarly, policies in the 'Moderate' stage should be developed in order to implement the policies in the 'Advanced' stage.

Transversal relationships refer to relationships among the policies in different dimensions and sub-dimensions. Although the policies have been divided into different sub-dimensions, these sub-dimensions are interrelated with each other. Therefore, within each maturity stage, the relationships among the sub-dimensions have been defined (see Fig. 3). These transversal relationships are maintained from one stage to the next one.

The Smart Mature Resilience System Dynamics model was built taking both linear and transversal relationships into consideration. As a result, when the policies are not implemented in the correct order, they will not be effective, and consequently, the user can inefficiently spend money on implementing policies out of order, without improving the city resilience level in terms of four different indicators computed by the model, namely: 'Leadership and Governance', 'Preparedness', 'Infrastructure and Resources', and 'Cooperation' indicators. The indicators' value is obtained through the average of the sub-dimensions, which are calculated based on the sum of the implementation rate of each policy on that sub-dimension multiplied by its effectiveness.

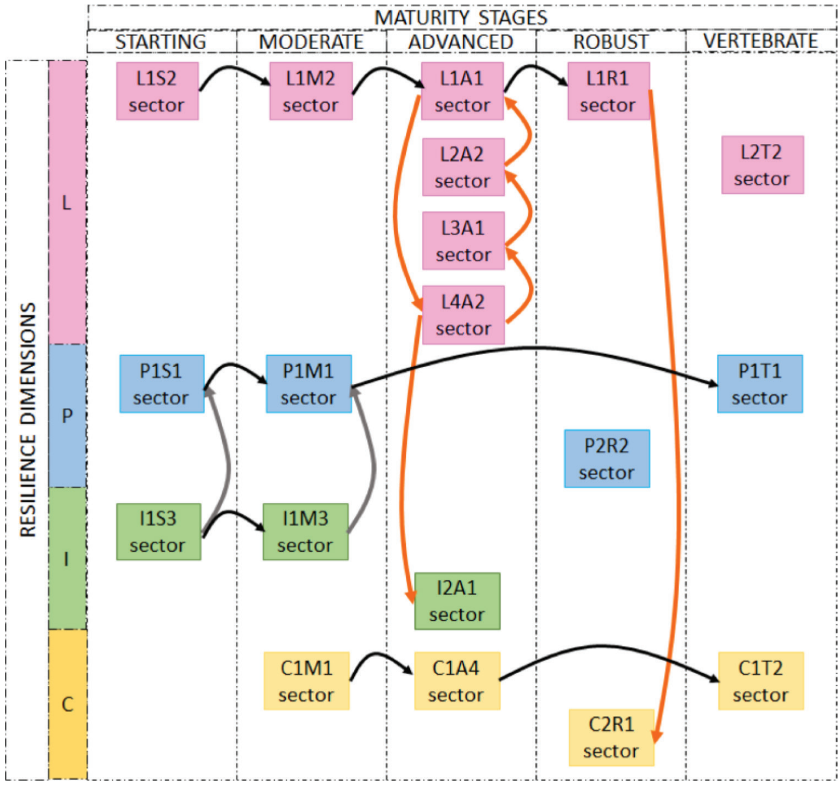

Figure 2: Linear and transversal relationships in the simplified Resilience Maturity Model. Black arrows for linear relationships and orange arrows for transversal relationships.

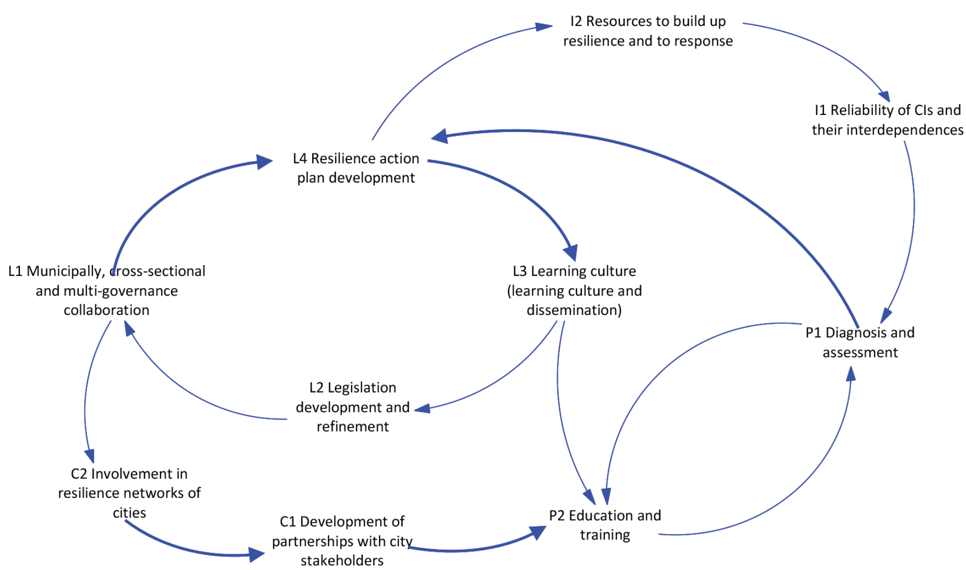

Figure 3: Transversal relationships at sub-dimension level.

4.2 Smart Mature Resilience System Dynamics based Interactive Learning Environment

The Interactive Learning Environment's GUI as mentioned above is web-based. It was developed using web technologies HTML, CSS, and JavaScript. The GUI is structured in three different views; *Initial* view (see Fig. 4), *Decisions* view (see Fig. 5), and *Results* view (see Fig. 6). The 'Initial' view enables users to enter the city's current resilience level, either by directly selecting one of the available SMART stages, or by setting individual policies' current implementation values. In this view, all the applicable policies organized according to their resilience dimension are shown with corresponding sliders to set these initial values. This view has two buttons: one button to recall a dialogue-box which sets the current SMART stage, and another button to change the view to the 'Decisions'. Similar to that 'Initial' view, the 'Decision' view shows all the applicable policies organized according to their resilience dimension. In addition, this view, shows the available budget, the current year of simulation, and 'Simulate' and 'Reset' buttons to advance simulation one step ahead and to stop the current simulation and start a new one respectively. This view also has a button to change the view to the 'Results' view. The 'Results' view summarizes the consequences of the taken

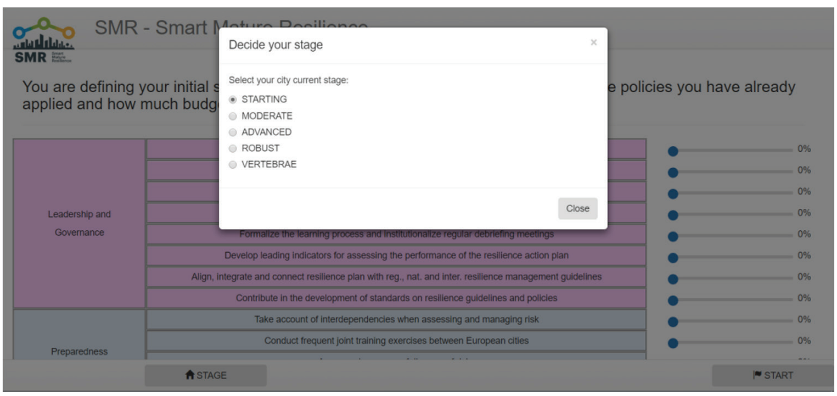

Figure 4: Initial view screen.

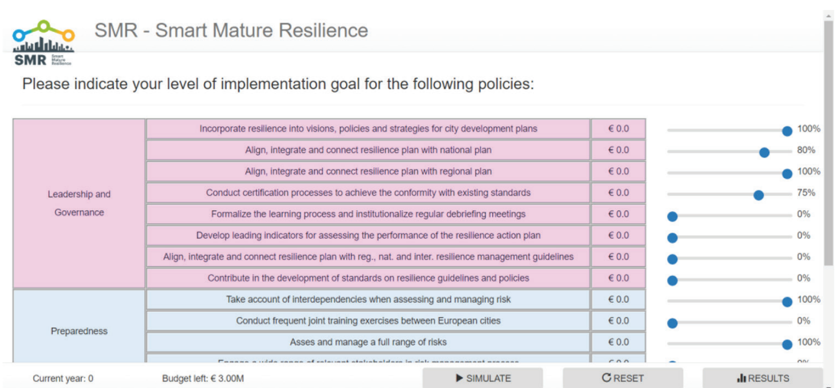

Figure 5: Decision screen.

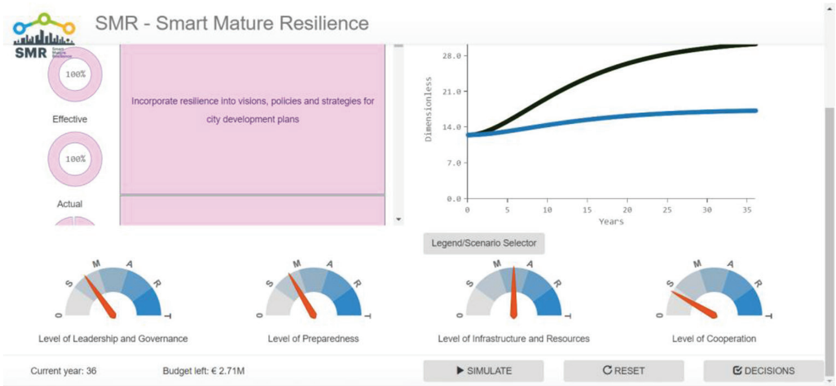

Figure 6: Results screen.

decisions through behaviour-over-time graphs for each of the four indicators mentioned above, implementation percentages for every policy and speedometers showing the resilience SMART maturity stage on the level of each of the four different indicators. Indicators behaviour-over-time graphs were able to show three different scenarios selected by the user, the code behind this behaviour-over-time graphs was adapted from Ref. [26, 27]. In this view the available budget, the current year of simulation, the 'Simulate' and 'Reset' buttons are shown, as well as a button to change the view back to the 'Decision' view.

The user will firstly establish the initial situation defining which maturity level the city is in. Afterwards, the simulation will start and the user will decide which policies implement and up to what percentage. In order to obtain some results and study the consequences of the implemented policies, the user will press the 'Simulate' button stepping forward two years every time. Consequently, the available budget will decrease and the 'Results' view will show the effects of the taken decisions. Apart from that, depending on the taken decisions, every four years the users will receive some pop-up help messages showing the errors they are committing regarding the precedence relationships and suggestions about which policies should be implemented to improve their performance.

5 WORKSHOP

In order to validate and assure the effectiveness of the Smart Mature Resilience pilot Interactive Learning Environment, a one-day workshop was carried out the 6th of March of 2017 with a total of 30 participants from the cities of *Bristol*, *Rome*, *Riga*, *Glasgow*, *Vejle*, *Kristiansand* and *Donostia* in addition to Smart Mature Resilience project academic partners: Tecnun, University of Navarra, The Centre for Integrated Emergency Management (*CIEM*) of the University of Adger, Linköping University (*LIU*), *University of Strathclyde* and the German Institute for Standardization (*DIN*).

The participants worked in small heterogeneous groups formed by people from different origins and with diverse backgrounds. The validation process had two main objectives: receive feedback from the users regarding the usability of the Interactive Learning Environment and validate the linear and transversal relationships that compose the logic of the causal relationships in the System Dynamics model.

Overall, the comments obtained from the participants were positive and they considered that the Interactive Learning Environment was useful for cities to better understand the

Resilience Maturity Model and therefore to train them to be well prepared for future crisis. However, they also made several comments to improve the tool.

6 RESULTS

The received feedback comments were classified depending on whether the comment was related to the System Dynamics model or the GUI.

6.1 The System Dynamics Model

Users found the results given by the model were coherent, yet some could be more realistic. In the following list, the most highlighted comments and suggestions are presented:

1. The Interactive Learning Environment defines the implementation level of a policy through a percentage applied by the user. However, participants pointed it would be more realistic to calculate the implementation level of a policy deciding the amount of resources the user wants to invest in each policy.
2. Regarding policy cost, the pilot version assumed all the policies cost the same. Nevertheless, the participants said it was not realistic to be so, each policy should have different unitary cost and their maintenance should be different too.
3. The Interactive Learning Environment defines the available budget from the beginning, and they pointed out it was not a realistic situation. Therefore, they suggested having an annual budget which could be defined by the user at the beginning and also have the opportunity to change it in the middle of the game in order to represent budget cuts.
4. The Interactive Learning Environment is based on policies' relationships which are defined with the same weight and importance. Participants suggested that in order to be more realistic, both linear and transversal relationships should have stronger or weaker relationships for each case and be more or less important to achieve resilience.

Once the suggestions were discussed, the 1st and 3rd comments were implemented in the new version of the model. For the cases of the 2nd and 4th suggestions, two questionaries' have been carried out in order to parameterize the values of the model.

6.2 The Graphical User Interface

In general, participants found the GUI visually easy to understand, yet not so intuitive. In the following list, the most highlighted comments and suggestions are presented:

1. In the GUI, only the names of the policies are shown, yet they are not defined. The participants suggested a brief explanation of the policy appear when the mouse hover over the policy name. This should help a user to better understand what he/she is implementing.
2. The policies in the GUI were classified only depending on their resilience dimension. However, the participants also asked to sort them depending on the maturity stage to facilitate understanding the implementation order.
3. The resulting graphs and percentages were just defined in the model's user guide. The participants suggested adding a brief explanation of the meaning of these graphs and percentages which appear when the mouse hover over these elements.
4. When defining the initial situation of the city in the Initial page, the participants were confused, as they thought they were already doing the simulation. Therefore, they asked

to differentiate more clearly when the user is defining the initial state and when the simulation starts.

5. Related to the indicators, they commented that the actual indicators were useful, yet the evolution of the spent money should also appear as a result. They suggested adding both a general behaviour-over-time graph with the evolution of the total budget and a specific graph with the budget spent on each resilience dimension as well.
6. In general, the comments related to the feedback messages were positive. However, a group of the participants found the messages to be too long to read comfortably. This group suggested highlighting the policies appearing in the feedback messages in the decisions-screen to easily identify them.
7. Considering that the Interactive Learning Environment the participants were using was a pilot version, they suggested that the final version should give them the opportunity to save the obtained results and be able to share them with colleagues.

After analysing the suggestions, some decisions were taken. For the suggestions 1, 2, 3, 5 and 6 the comments of the participants were implemented in the updated version of the model. In the case of suggestion 4, a third screen with a brief explanation of the model has been designed which appears at the beginning of the simulation. Finally, for the 7th suggestion, the updated version not only enables to save the results but to download them and send them to any other player.

7 CONCLUSION

Disasters are increasing significantly lately leading to a pressing need for developing city resilience. However, there is a lack of practical examples, which provide sequential steps toward building resilience. In this context, the European project 'Smart Mature Resilience' appears with the objective of developing Resilience Management Guideline based on 5 tools. One of these tools is a System Dynamics model, which is encapsulated in an Interactive Learning Environment. Interactive Learning Environments have been recently used for didactical objectives to train and give users better understanding of the issues addressed, as they have shown to provide high benefits compared to traditional methods. Therefore, the main objective of our System Dynamics model is to provide a tool to better understand both the Resilience Maturity Model and the most appropriate path to gain resilience.

This paper presents a beta version of the System Dynamics Interactive Learning Environment developed for the Smart Mature Resilience project. The presented beta version is evaluated and validated through a workshop from which the most highlighted comments are also presented and discussed in this paper. The paper concludes with a set of requirements the Interactive Learning Environment and the System Dynamics model must fulfil in the final version.

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