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Supporting flexible regulation of crisis management by means of situated artificial institution*#

Maiquel DE BRITO†1, Lauren THÉVIN[2], Catherine GARBAY[2],
Olivier BOISSIER[3], Jomi Fred HÜBNER[1]
([1]Federal University of Santa Catarina, UFSC/CTC/DAS/PPGEAS - PO Box 476, Florianópolis, SC 88040-900, Brazil)
([2]LIG/Université de Grenoble, Grenoble 38041, France)
([3]Laboratoire Hubert Curien UMR CNRS 5516, Institut Henri Fayol, MINES Saint-Etienne, Saint-Etienne 42023, France)
†E-mail: maiquel.b@posgrad.ufsc.br

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Abstract: This paper highlights the use of situated artificial institution (SAI) within a hybrid, interactive, normative multi-agent system to regulate human collaboration in crisis management. Norms regulate the actions of human actors based on the dynamics of the environment in which they are situated. This dynamics results from both environment evolution and actors' actions. Our objective is to situate norms in the environment in order to provide a context-aware crisis regulation. However, this coupling must be a loose one to keep both levels independent and easy-to-change in order to face the complex and changing crisis situations. To that aim, we introduce a constitutive level between environmental and normative states providing a loose coupling of normative regulation with environment evolution. Norms are thus no more referring to environmental facts but to status functions, i.e., the institutional interpretation of environmental facts through constitutive rules. We present how this declarative and distinct SAI modelling succeeds in managing the crisis with a context-aware crisis regulation.

Key words: Situated artificial institutions (SAIs), Normative system, Tangible interaction, Crisis management
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1 Introduction

Crisis management aims at organising a response to disasters, within natural or artificial accidents, to limit material and human damages. It corresponds to a complex decentralised collaborative activity involving various actors and organisations (e.g., firefighters, police, citizens). They act and coordinate altogether in a highly dynamic and uncertain environment to take efficient and consistent actions related to multiple missions (e.g., information, security, supply, lodging).

Crisis management collaborative platforms are increasingly used in such a context. In this direction, we are currently developing such a platform based on tangible tables to mediate the opportunist interaction among the involved distant actors. To consider and enact crisis management and norms used to coordinate the collective actions of the actors, we have proposed a normative multi-agent based approach to define a socio-technical system (Thévin *et al.*, 2014) where humans and software agents cooperate with each other (i.e., hybrid system) by combining physical, digital, and virtual interactions (i.e., mixed interaction) that are regulated by norms (i.e, normative system). These three pillars are well adapted to tackle the challenges raised by crisis management systems.

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ORCID: Maiquel DE BRITO, http://orcid.org/0000-0003-4650-7416

This paper addresses an additional and important feature to develop such a system. It deals with the coupling of the norm-based regulation with the physical environment where the collaboration on crisis management takes place. Norms are usually specified considering the domain to be regulated rather than the concrete elements involved in the collaboration. For example, in a crisis scenario, norms are specified in terms of firefighters, evacuations, etc., rather than in terms of the agents acting as firefighters or the concrete actions employed to perform evacuations. This feature requires to situate the norms in the environment, defining, for example, who are the firefighters and what are the actions that mean an evacuation. The approach used to situate norms in the environment should be flexible and easy-to-change in order to face the complex and changing crisis situations. Indeed, two problems may occur: (1) discrepancies in the interpretation of events issued from the environment, depending on context, role, or actor's organisation, and (2) inconsistencies of human intervention due to inconsistencies between the systems of norms for different organisations.

We have initially addressed the above mentioned problems in de Brito *et al.* (2015b), dealing with the coupling of the norm-based regulation in the physical environment in which the crisis takes place. Situating norms and regulations in the environment should be realised in a flexible and easy-to-change way to face the complex and changing crisis situations. In that initial work we turned to the situated artificial institution (SAI) model (de Brito *et al.*, 2014), which offers the right abstractions and constructs to resolve this problem. Through an application prototype, we show what SAI can bring to the development of the real crisis management application. This paper extends that previous work (de Brito *et al.*, 2015b) presenting an extended use case and providing additional details about the SAI model. We also go deeper in the analysis of the contributions of situatedness provided by SAI to the crisis management collaboration platform.

2 Principles and requirements

2.1 Use case example

We will consider a simplified but rich enough use case of crisis management where the goal is to deal with the evacuation of zones affected by a crisis. The actors, in this activity, are organised in three groups: a communal command post (CCP) under the responsibility of the mayor, a logistic cell (LC) and a support cell (SC), both controlled by the CCP, and the firefighters (FFs). Zones are classified as secure and insecure. Unprofessional people can deal with the evacuation of secure zones (mayor commanding and both LC and SC executing). The insecure zones require professional stakeholders such as FFs to realise evacuations. The operational command post (OCP) centralises and coordinates operational actions (i.e., fieldwork). The OCP is under the responsibility of the firefighters. The representative of the mayor at the OCP is responsible for communication and coordination with the CCP.

The mayor is responsible for coordinating the evacuation of secure zones by commanding the LC and the SC. FFs are the only responsible for evacuating insecure zones. When a zone is completely evacuated, the SC is responsible for registering the evacuated people. Sensors, databases, geographic information systems (GISs), etc. provide information about the environmental variables involved in the crisis (e.g., rainfall indexes, Richter scale grades). For simplicity, this paper considers that the only information provided by these elements is the phase of the crisis in each zone: preventive (less severe) and emergency (more severe)—managed under dedicated policies. It is not assumed that sensors, databases, GISs, etc. can evaluate and classify the phase of a crisis. The names 'preventive' and 'emergency' are used to make the example more illustrative. In real scenarios, however, depending on the information source, the information may have different identifiers. When a crisis takes place, independent of its phase, the mayor is obliged to designate his/her representative at the OCP. The named representative is responsible for establishing a permanent link between OCP and the mayor by regularly sending reports.

These actors work under several policies and norms. A policy is a set of norms and plans, where norms govern all the agents and plans are addressed to specific agents that are the interface between government and society (da Silva dos Santos and da Rocha Costa, 2009). A first norm in one of the policies specifies that there must be only one group of actors at a time to manage an evacuation.

Depending on the status of the zone (either secure or insecure), it is the duty of either the mayor and his/her subordinates (LC and SC) or FFs to intervene. However, qualifying a zone as secure or risky may appear conflicting. For the mayor, a zone is considered as secure as long as the phase of the crisis is preventive and the number of inhabitants is less than a threshold. Contrarily, for the actors belonging to the FF group, the security of a zone depends on the fact that the phase is preventive and that there is no electrical risk in that zone, whatever the number of inhabitants is. Suppose now that we are in a preventive phase, that the number of inhabitants exceeds the threshold, and that there is no electrical risk. In this case, the mayor will consider that the FFs are responsible for the evacuation, while the FFs will consider the reverse: the mayor is responsible for evacuating the zone. This small example illustrates the possible existence of discrepancies in the interpretation of events coming from the environment, depending on context, role, or organisation; it also shows inconsistencies of human intervention due to inconsistencies between sets of policies from different organisations.

As another example, suppose that the mayor is obliged to command the evacuation of a zone when the crisis is in the preventive phase. Due to crisis evolution, however, the phase moves from preventive to emergency phase. This will result in an evolution of the current norms. As a consequence, the mayor becomes prohibited to command the evacuation, while the FFs become obliged to do that. This illustrates an additional issue related to the potential evolution of norms.

Even when the norms remain stable, the means employed by the agents to comply with them may change. For example, the SC is obliged to support the LC in the evacuation procedures. The way to provide this support may be different according to the crisis context. For example, in less serious crisis, such a support could consist of SC informing the LC about the weather conditions, while in more severe situations, the support could be the physical presence of SC in the affected zone.

2.2 Hybrid, mixed, and normative dimensions

As seen before, crisis management is a collaborative activity where the actions of human actors have to be efficient and flexible to tackle the unpredictable evolution of the situations. From the analysis of existing approaches in crisis management, groupware, and multi-agent systems (MASs), the system needs to rely on hybrid, mixed, and normative pillar dimensions.

1. Hybrid multi-agent system: mixing human and artificial agents

Crisis management is a complex collaborative activity where multiple actors and organisations participate. They act and coordinate to take efficient actions related to multiple missions (e.g., information, security, supply, lodging), in a highly dynamic and uncertain environment. Given the inherent distributed and decentralised nature of crisis management, a multi-agent approach is well suited: human and artificial actors are considered as agents interacting with each other in a shared environment under the control of regulation and coordination policies that are organisation and context dependent.

2. Mixed interactions: mixing tangible, numerical, and virtual modalities

To tackle the distributed dimension inherent to crisis management, the system is deployed on a network of TangiSense tables (Kubicki *et al.*, 2012) through which human actors interact. These tables can detect and locate tangible objects equipped with radio frequency identification (RFID) tags. Their surface is further equipped with a liquid-crystal display (LCD) allowing a virtual display of complex simulations as well as virtual feedback connected to tangible objects. The choice of this technology is motivated by its ability to support flexible and opportunistic activity. To support organisational context awareness (Garbay *et al.*, 2012), i.e., to enable the actors to perceive the roles, missions, and norms of the other actors, we further exploit feedbacks to figure out the inconsistencies and conflicts that may arise during collaboration with respect to the regulation and coordination policies.

3. Normative system

Collaboration is challenging in crisis management due to the lack of resources, changes in the situations, and decentralised inter-organisational activity (Dugdale *et al.*, 2010). Such a complexity requires that the different actors act according to certain behavioural expectations. Norms and normative systems, as defined in Boella *et al.* (2008), provide proper abstractions and mechanisms to express this expected behaviour, thus regulating the decentralised activities in dynamic and unpredictable environments. Beyond regulating human coordination activity, norms manage the agent's degree of autonomy and task allocation among the human/agent community. Finally, norms guide man–machine interaction, describing what are the permitted actions for human actors (production activity) and how to proceed to feedback generation (communication activity).

We have used these three pillars to conceive a normative multi-agent system to support crisis management. This system is used to regulate mixed interactions between human and artificial actors: human agents play a crisis management scenario while artificial agents monitor their activity and implement the interaction.

2.3 Supporting human mediated collaboration in a situated way

In the system built from the pillars, three normative specifications are considered to deal with the three activity spaces required to enable a complex collaborative interaction: production, coordination, and communication.

Our goal is to anchor norms into the environment while keeping their definition the most independent as possible of the physical world. To this end, we introduce an intermediate level formalised by the interpreted facts (Table 1, row 5) on which the regulation is based. These facts are the result of the interpretation rules (Table 1, row 4) applied to the elements of the physical world (Table 1, row 3). We thus follow the decomposition presented in Table 1 where the interpretation occurring in each activity space is described. In this table, the interpreted facts in column i of the 5th row become the physical facts in column $i+1$ of the 3rd row.

The first step (Table 1, column 2) is to interpret the tangible inputs (row 3) as figurative actions (row 5), through the interpretation rules (row 4). These figurative actions are then judged as either valid or invalid regarding the production activity norms (row 7). The aim is to answer whether the activity pattern is a valid interaction with respect to the tangible input rules.

The valid figurative actions are then interpreted as declarations, missions, or roles through the interpretation rules (Table 1, column 3). They are then judged as valid or invalid regarding the coordination activity norms. The aim in this step is to check whether the environmental elements, under a proper interpretation on the context of crisis management, are those expected.

Finally, from these successive interpretations, virtual feedbacks are produced in the physical world to represent the declarations, missions, and roles recognised as valid. These virtual feedbacks are delivered according to proper rules (Table 1, column 4). The aim in this step is to define where and how to deliver virtual feedbacks so that fluent communication takes place among the actors.

To illustrate the declarative power of our model, we focus on the coordination space (Table 1, column 3) and consider the potential discrepancies between the mayor and FFs' interpretation of the notion of 'secure zone'. As we will see in Section 4, these discrepancies can be solved through two different ways to ground the notion of 'secure zone' in the environment (i.e., by two different institutional interpretations of the environment), while keeping the normative specification independent of these discrepancies. Regarding the potential evolution of norms, from preventive to emergency phases, the proposed modelling allows changes in the way we manage a situation (actor's roles), while keeping its interpretation of the environmental state stable.

3 Situated artificial institution

The philosopher John Searle investigated how a world composed of brute facts described in terms of physics, chemistry, and other basic sciences gives rise to a world composed of institutional facts such as money, property, and marriage, which cannot be explained by the same basic sciences (Searle, 1995; 2009). Searle claimed that, in human societies, some brute facts 'count as' (or 'constitute') institutional facts and such constitution is the basis for human institutions to define obligations, prohibitions, permissions, etc. For example, a fence being placed around a site counts as the boundary of a private property. People are thus forbidden to enter the site not because the fence is insurmountable, but because it is recognised as (i.e., it 'counts as') the boundary of a private property.

The SAI model is inspired by this theory. It is based on environmental elements, status functions,

Table 1 Situating production, coordination, and communication norms in the environment

Layer/Space	Production	Coordination	Communication
Physical			
Environment	Tangible inputs	Figurative actions	Declarations, missions, roles
Interpretation rules	Action interpretation rules from tangible inputs	Organisation interpretation rules	Virtualisation rules
Interpreted facts	Figurative actions	Declarations, missions, roles	Virtual feedbacks
Organisation			
Norms	Action validity	Declarations, missions, role validity	Virtual feedback validity

constitutive rules, and norms, arranged to allow the regulation of MAS based on facts occurring in the environment (Fig. 1) (de Brito *et al.*, 2014). As in the normative system pillar, norms define what the agents are obliged and forbidden to do. Norms refer to an abstract level that is not directly related to the environment. For example, the norm stating that "the winner of an auction is obliged to pay its offer" specifies neither who is the winner that is obliged to fulfil the norm nor what the winner must concretely do to fulfil it. The effectiveness of a norm depends on its connection to the environment as its dynamics (activation, fulfilment, etc.) is the result of facts occurring there. The norms are connected to the environment when their components—the status functions—are constituted from the environment according to the specified constitutive rules. In the sequel, some details of this connection—inspired by the notion of 'constitution' proposed by Searle—are presented so that the SAI application to the crisis scenario can be developed in the next section.

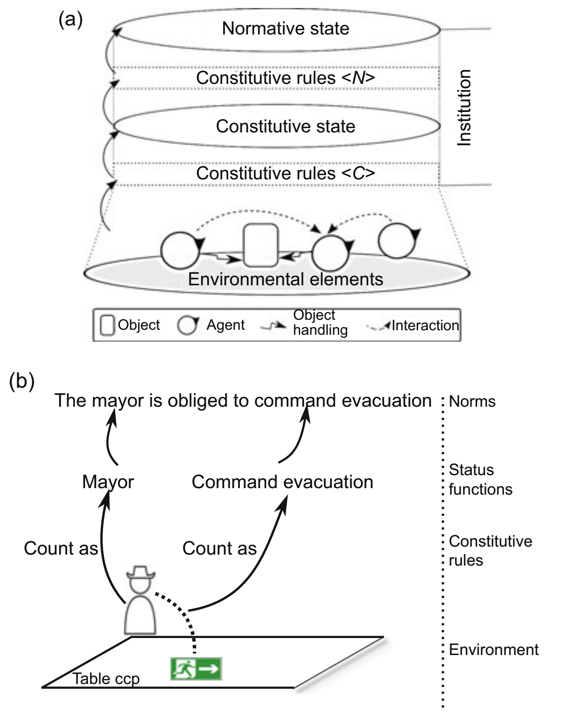

Fig. 1 Situated artificial institution overview: abstract overview (a) and overview on crisis management (b)

3.1 Environmental elements

The literature on MAS usually considers environment as a set of non-autonomous elements that are perceived by the agents and which they act upon to achieve their goals (Russell and Norvig, 2003; Weyns *et al.*, 2007; Ricci *et al.*, 2011). From the SAI perspective, the environment is also composed of the agents that act upon and perceive the non-autonomous elements. The environmental elements, source of brute facts of interest in SAI, are represented by $\mathcal{X} = \mathcal{A}_\mathcal{X} \cup \mathcal{E}_\mathcal{X} \cup \mathcal{S}_\mathcal{X}$ such that (1) $\mathcal{A}_\mathcal{X}$ is the set of agents possibly acting in the system, (2) $\mathcal{E}_\mathcal{X}$ is the set of events that may happen in the environment, and (3) $\mathcal{S}_\mathcal{X}$ is the set of properties used to describe the possible states of the environment. Agents in $\mathcal{A}_\mathcal{X}$ are represented by atoms (e.g., bob). Events in $\mathcal{E}_\mathcal{X}$ are pairs (e, a) where e is an atom identifying the event followed by some possible arguments (e.g., offer(100)) and a is an atom identifying the agent that has triggered event e. Properties in $\mathcal{S}_\mathcal{X}$ are represented by first-order logic predicates. It is beyond the scope of this paper to deal in detail with the environment. We just consider the elements of $\mathcal{X}$ as existing outside the institution, being available thanks to reliable interfaces. From the institutional point of view, these environmental elements may carry some status functions (Searle, 2009).

3.2 Status functions

Status functions are functions that the environmental elements (agents, events, and states) perform from the institutional perspective (Searle, 2009). For example, in a certain institution:

1. An agent may have the function of auctioneer. However, it has such a function due to an institutional assignment. The agent may be implemented with expertise to be an auctioneer and may intend to be an auctioneer, but without the institutional assignment of the status function auctioneer, it will not be considered at the institutional level as playing that function.

2. The event corresponding to the utterance of "I offer \$10 000" may have the status function of 'bid' or 'counter-proposal', depending on the institutional assignments.

3. The state that "more than 20 people are inside a room at Friday 10 am" may mean, in the institution, the minimum quorum for an auction.

The status functions of an SAI are formally represented by $\mathcal{F} = \mathcal{A}_{\mathcal{F}} \cup \mathcal{E}_{\mathcal{F}} \cup \mathcal{S}_{\mathcal{F}}$, where (1) $\mathcal{A}_{\mathcal{F}}$ is the set of agent-status functions (i.e., status functions assignable to agents), (2) $\mathcal{E}_{\mathcal{F}}$ is the set of event-status functions (i.e., status functions assignable to events), and (3) $\mathcal{S}_{\mathcal{F}}$ is the set of state-status functions (i.e., status functions assignable to states). Agent-status functions are represented by atoms. Event-status functions are represented by an atom followed by some possible arguments. State-status functions are represented by first-order logic predicates.

The previously described elements are used to write e-formulae $w_{\mathcal{X}} \in W_{\mathcal{X}}$ and sf-formulae $w_{\mathcal{F}} \in W_{\mathcal{F}}$ following the grammar rules (1) and (2) below. These formulae will be used later to express conditions in the constitutive rules—their semantics was detailed in de Brito *et al.* (2015a). Briefly, an e-formula $w_{\mathcal{X}}$ is true when it refers to events actually occurring and states actually holding in the environment. An sf-formula $w_{\mathcal{F}}$ is true when it refers to event- and state-status functions actually assigned to some environmental element or, in the case of an sf-formula like 'x is y', when an environmental element x actually carries the status function y.

$$w_{\mathcal{X}} ::= e_{\mathcal{X}} | s_{\mathcal{X}} | \neg w_{\mathcal{X}} | w_{\mathcal{X}} \vee w_{\mathcal{X}} | w_{\mathcal{X}} \wedge w_{\mathcal{X}} | \bot | \top, \quad (1)$$

$$w_{\mathcal{F}} ::= e_{\mathcal{F}} | s_{\mathcal{F}} | \neg w_{\mathcal{F}} | w_{\mathcal{F}} \vee w_{\mathcal{F}} | w_{\mathcal{F}} \wedge w_{\mathcal{F}} | x \text{ is } y | \bot | \top, \quad (2)$$

$$\text{s.t. } e_{\mathcal{X}} \in \mathcal{E}_{\mathcal{X}}, s_{\mathcal{X}} \in \mathcal{S}_{\mathcal{X}}, e_{\mathcal{F}} \in \mathcal{E}_{\mathcal{F}}, s_{\mathcal{F}} \in \mathcal{S}_{\mathcal{F}},$$

and x and y are logical literals.

The assignment of status functions of $\mathcal{F}$ to the environmental elements of $\mathcal{X}$ is specified through constitutive rules.

3.3 Constitutive rules

A constitutive rule $c \in \mathcal{C}$ is a tuple $\langle x, y, t, m \rangle$ meaning that x ($x \in \mathcal{F} \cup \mathcal{X} \cup \{\varepsilon\}$) counts as (i.e., x has the status function) y ($y \in \mathcal{F}$) when event t ($t \in \mathcal{E}_{\mathcal{F}} \cup \mathcal{E}_{\mathcal{X}} \cup \top$) has happened and while the formula m ($m \in W_{\mathcal{X}} \cup W_{\mathcal{F}}$) holds in the environment or in the institution. ε represents that the element x is irrelevant in the constitutive rule. The constitutive rule, in this case, determines a freestanding assignment (Searle, 2009; de Brito *et al.*, 2014). When $t = \top$, the assignment does not depend on any event. If a status function y is assigned to x, we say that x constitutes y.

The interpretation of the constitutive rules considering the current environmental state, which produces the constitution of the status functions, is formalised and detailed in de Brito *et al.* (2015a). Briefly, for a constitutive rule $\langle x, y, t, m \rangle$:

1. If $y \in \mathcal{A}_{\mathcal{F}}$, then agent x will carry agent-status function y from the instant when event t occurs, while state m holds and while the very agent x is participating in the system.

2. If $y \in \mathcal{E}_{\mathcal{F}}$, then event x will carry event-status function y in the instant when the very x occurs, subject to the simultaneous occurrence of event t and to the holding of state m.

3. If $y \in \mathcal{S}_{\mathcal{F}}$, then property x will carry state-status function y from the instant when the event t occurs, while state m holds and while the very property x is holding. In the case of a freestanding assignment (i.e., if $x = \varepsilon$), state-status function y just holds in the institution instead of being assigned to a property x.

3.4 Norms

We consider here a norm as a tuple $n = \langle c_{\mathrm{a}}, a, d, i, c_{\mathrm{d}} \rangle$ where: (1) c_{a} is the activation condition of the norm, expressed by event- and state-status functions; (2) a is the agent-status function pointing to the agent targeted by the norm; (3) $d \in \{\text{obliged}, \text{prohibited}\}$ is the deontic operator of the norm; (4) i is the goal to achieve (when d=obliged) or to avoid (when d=prohibited), expressed either by an event-status function or by a state-status function; and (5) c_{d} is the optional event- or state-status function pointing to the deadline to satisfy the norm.

The dynamics of the lifecycle of the norms is illustrated in Fig. 2: obligations and prohibitions become active when the activation condition $c_{\rm a}$ is satisfied; obligations are fulfilled when aim i is satisfied before deadline $c_{\rm d}$; prohibitions are fulfilled when i remains unsatisfied until deadline $c_{\rm d}$. For example, in an auction scenario, the tuple

$$\langle \text{auction\_finished}, \text{winner}, \text{obliged}, \\ \text{to\_pay}, \text{payment\_deadline} \rangle$$

expresses that, when some environmental state counts as auction_finished, the agent that counts as winner is obliged to produce an event that counts as to_pay before the system to reach a state that counts as payment_deadline. The satisfaction of the conditions $c_{\rm a}$, i, and $c_{\rm d}$, and the set of agents carrying the status function a targeted by the norm, are checked with respect to the constitutive state.

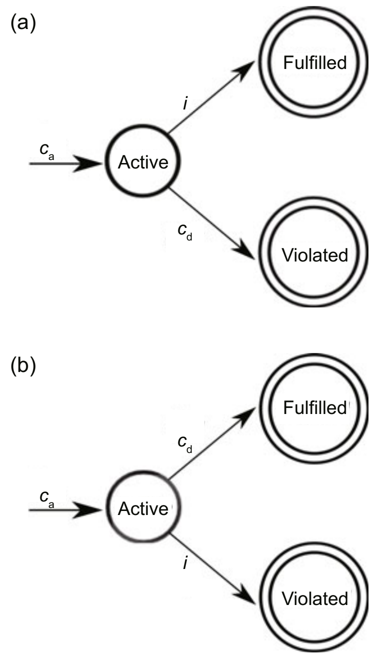

Fig. 2 Lifecycle of obligations (a) and prohibitions (b)

The model of norm used in this study is simple as our focus is on situating the norms rather than on the norms themselves. For simplicity, aspects such as sanctioning and repairing of norm violations, present in other normative models, are ignored (Vázquez-Salceda *et al.*, 2004; y López *et al.*, 2006; Panagiotidi *et al.*, 2013). A more complex model including reparations of violations has its regulation based on SAI in de Brito *et al.* (2016).

A language to specify SAI was proposed in de Brito *et al.* (2014). Section 4.5 shows a specification according to that language.

4 Situated artificial institution for crisis management applications

The use case described in Section 2 is realised with the hybrid normative MAS deployed on top of a network of tangible tables to support mixed interactions. The environment in which agents interact thus corresponds to the events and states produced by the actions of human actors on the tables. Since the acting of the human actors in the environment does not have per se any meaning in crisis management, SAI constitutive rules enable to institutionalise facts occurring in the environment, and to give them the proper meaning in the particular application (e.g., the tangible B in the position (C, D) counts as a command to evacuate the downtown). Such institutionalisation is important to the regulation of the scenario, that is, ultimately, the regulation of the activities of the human actors in the environment (Fig. 1b). Section 4.1 describes the relevant aspects of the environment in the proposed use case. Sections 4.2 to 4.4 explain how the SAI elements provide meaning to the tangible interactions enabling their regulation.

4.1 Crisis management SAI environment

In this particular application, the environment is composed of data sources (GIS, databases, etc.), of sensors such as clocks, and of the whole set of (possibly distributed) tangible equipments involved in the application. The agents interacting in crisis management are also represented as environmental elements (cf. Section 3.1).

It is assumed that the human actors check in the tables before taking part in crisis management. They use three kinds of tangible objects: launch_tangible to launch actions, alert_tangible to issue alerts, and message_tangible to send messages. Among all the events possibly occurring in the environment, the relevant ones here are (1) `checkin(AgentID, TableID)`, triggered when the agent `AgentID` checks into the table `TableID`, (2) `putTangible(TableID, TangiID, X, Y, AgentID)`, triggered when the agent AgentID puts either a launch_tangible or an alert_tangible TangiID on the coordinates (X,Y) of TableID, and (3) putTangible(TableID, TangiID, X, Y, Target, Content, AgentID), triggered when the agent AgentID uses a message_tangible to send a message to Target informing some Content. Note that here elements in true type font appear in the SAI specification (Section 4.5) and terms starting with upper-case letters are variables.

The relevant environmental properties that compose the environmental state, provided by databases, GIS, etc., are (1) nbInhabitants(ZoneID, X) holding when the ZoneID has X inhabitants and (2) security_phase(ZoneID, Phase) holding when the ZoneID is on the security Phase (s.t. Phase∈{preventive,emergency}).

4.2 Crisis management SAI status functions

The environmental dynamics described in Section 4.1 animates the institutional dynamics when it gives rise to the constitution of the status functions. In the following, we define the relevant status functions in the presented use case (as defined in the program in Section 4.5).

1. The agent-status functions define that agents act in the scenario as (1) mayor of the town (mayor), (2) member of the LC (logistic_cell), (3) member of the SC (support_cell), (4) firefighter, or (5) the representative of the mayor in the OCP (representative_ocp).

2. The event-status functions define that events occurring in the environment can mean in the institution (1) the command for an Evacuator to evacuate a Zone (command_evacuation(Zone,Evacuator)), (2) the performance of an evacuation of a Zone (evacuate(Zone)), (3) the support of the evacuation of a Zone (support_evacuation(Zone)), (4) the registration of the evacuated people (register_evacuated_people(Zone)), and (5) the appointment of the representative of the mayor at the OCP (name_representative_ocp).

3. The state-status functions define that the system can be in states where, from the institutional perspective, (1) a Zone is considered secure for security procedures (secure(Zone)), (2) a Zone is insecure (insecure(Zone)), (3) a Zone is electrically risky (electrical_risky(Zone)), and (4) the expected time to send information is expired (max_time_to_inform).

Notice that, although some status functions have names alluding to elements of the concrete world, such as 'electric' and 'time', they are not environmental elements. The status functions have these names to be more illustrative in this paper. Naming status functions is part of the design of the institutional ontology and it is up to the designer to properly choose the names.

4.3 Crisis management SAI constitutive rules

As for the status functions, three sets of constitutive rules are considered:

1. Agent status function constitutive rules

Rules 1 to 4 shown in Section 4.5 specify that the agent-status functions of mayor, logistic_cell, support_cell, and firefighter are constituted by the Agent that checks into the proper Table producing the event checkin(Table, Agent). The while clause of rule 1 still ensures that the status function of mayor is assigned only to a single agent at a time as it defines that the agent keeps carrying such a status function while it is not assigned to another agent or while it is assigned to the Agent itself. Rule 5 specifies that an agent counts as the representative of the mayor at the OCP when it receives from the mayor a message whose content is represent_mayor_ocp.

2. Event status function constitutive rules

Rules 6 to 11 shown in Section 4.5 define that some tangible interactions mean, in the institution, the command of an evacuation, the execution of an evacuation, and the support to an evacuation. This meaning is conditioned to the tangible object used in the interaction and also to the Actor that performs the interaction. In addition to defining the kind of action from the institutional perspective, these constitutive rules define correspondences between different points of the tables and different geographic zones. As a result, we can consider that the coordinates (1,2) are related to the downtown while the coordinates (3,3) are related to the industrial zone.

3. State status function constitutive rules

By rule 14 shown in Section 4.5, the property security_phase(Zone,preventive) holding in the environment counts as the Zone being secure for unprofessional people to deal with the security. By the first part of the while clause, such relation between environmental state (the zone in the preventive phase of crisis management) and institutional state (the zone being secure) holds while the zone does not pose electrical risks. Besides, by the remaining part of the `while` clause, such relation holds when the zone has, at most, 500 inhabitants or if it is already secure. Thus, (1) if the property `security_phase(Zone,preventive)` starts to hold when the zone has more than 500 inhabitants, the zone is not considered secure and (2) a zone remains secure even if its number of inhabitants changes exceeding the threshold. Note that, if `security_phase(Zone,preventive)` does not hold in the environment, it cannot carry the status function `secure(Zone)`. Rules 15 and 16 define an `insecure(Zone)` from the institutional perspective. Rule 17 defines what constitutes an electrically risky zone. It specifies a 'freestanding' assignment since there is not a concrete element in the environment to carry the status functions. The constitutive rule 18 specifies that the institution considers the `clock` showing a value multiple of 60 000 as the deadline for reporting information (the clock, in this case, is a counter incremented every millisecond).

4.4 Crisis management SAI norms

The norms in Section 4.5 define prohibitions and obligations related to the command for evacuations and to the evacuations. Notice that the norms do not refer directly to the environment. Rather, they refer to status functions. For example, norm 1 specifies when the agent carrying the status function of mayor is obliged to produce any event that means, in the institution, the command of an evacuation. LC and SC are obliged to react in different ways to this command (norms 5 and 6). Notice that the actions of LC and SC are triggered by the command of the mayor independent of a zone being considered secure or insecure. This is why the mayor is prohibited to command evacuation of insecure zones: to prevent LC and SC, which are non-professional teams, to act when they are not expected to do so. FFs are prohibited to evacuate secure zones (norm 3) but are obliged to evacuate insecure zones (norm 4). With this set of norms—1 to 6—we clearly define the expected coordinated behaviour of the different actors with respect to the evacuation activities. Norm 7 defines that, after a zone is evacuated by any actor, the SC is obliged to register the evacuated people. Norm 8 specifies that, if there is at least one zone in any phase of crisis, then the mayor must name their representative at OCP. By norm 9, this representative is always obliged to keep a link between the mayor and the OCP.

4.5 SAI specification

The SAI specification for the proposed use case is shown below:

```
status_functions:
  agents: mayor, firefighter, logistic_cell,
          support_cell, representative_ocp.
  events: command_evacuation(Zone), evacuate(Zone),
          support_evacuation(Zone),
          register_evacuated_people(Zone),
          name_representative_ocp, link_mayor_ocp.
  states: secure(Zone), insecure(Zone), electric_risky(Zone),
          max_time_to_inform.

norms:
/*The mayor is obliged to command evacuations of secure zones*/
1: secure(Zone): mayor obliged command_evacuation(Zone)
              until not(secure(Zone)).
/* The mayor is prohibited to command evacuations of insecure
zones */
2: insecure(Zone): mayor prohibited command_evacuation(Zone)
              until not(insecure(Zone)).
/* The firefighter is prohibited to evacuate secure zones */
3: secure(Zone): firefighter prohibited evacuate(Zone)
              until not(secure(Zone)).
/* The firefighter is obliged to evacuate insecure zones */
4: insecure(Zone): firefighter obliged evacuate(Zone)
              until not(insecure(Zone)).
/* The logistic_cell is obliged to evacuate a zone when a
command is emitted */
5: command_evacuation(Zone): logistic_cell obliged
        evacuate(Zone).
/* The support cell is obliged to support the evacuation of a zone
when a command is emitted */
6: command_evacuation(Zone): support_cell obliged
        support_evacuation(Zone).
/* The support_cell is obliged to register evacuated people */
7: evacuate(Zone): support_cell obliged
        register_evacuated_people(Zone).
/* If there is at least one zone in any phase of crisis, mayor must
name his/her representant on OCP*/
8: secure(Zone)|insecure(Zone): mayor obliged
        name_representant_ocp.
/* The mayor's representant in OCP is always obliged to keep a
link between mayor and OCP*/
9: true: representant_ocp obliged link_mayor_ocp
              until max_time_to_inform.

constitutive_rules:
/*** Agent-status functions constitutive rules ***/
/*Actors carry the status functions according to their check in
the tables*/
1: Agent count-as mayor
       when checkin(table_ccp,Agent)
         while not(Other is mayor)|Other==Agent.
2: Agent count-as logistic_cell
       when checkin(table_logistic_cell,Agent).
3: Agent count-as support_cell
       when checkin(table_support_cell,Agent).
4: Agent count-as firefighter
       when checkin(table_fire_brigade,Agent).
/* An actor is the mayor's representative at the OCP when the
mayor sends the naming message */
```

```
5: Target count-as representant_ocp
    when putTangible(Table,message_tangible, X, Y,
            Target,represent_mayor_ocp)[sai__agent(Actor)]
    while Actor is mayor.

/*** Event-status functions constitutive rules ***/
/* The mayor putting the object launch_tangible in the
coordinates 1,2 of any table counts as the command to
evacuate the downtown*/
6: putTangible(_,launch_tangible,1,2)[sai__agent(Actor)]
    count-as command_evacuation(downtown)
    while Actor is mayor.
/* Firefighter and logistic cell putting the object
launch_tangible in the coordinates 1,2 of any table counts as
the evacuation of the downtown */
7: putTangible(_,launch_tangible,1,2)[sai__agent(Actor)]
    count-as evacuate(downtown)
    while Actor is firefighter | Actor is logistic_cell.
/* The support cell putting the object launch_tangible in
the coordinates 1,2 of any table counts as supporting the
evacuation of the downtown */
8: putTangible(_,launch_tangible,1,2)[sai__agent(Actor)]
    count-as support_evacuation(downtown)
    while Actor is support_cell.
/* Rules 9 to 11: similar to 6 to 8, but related to the
industrial zone */
9: putTangible(_,launch_tangible,3,3)[sai__agent(Actor)]
    count-as command_evacuation(industrial_zone)
    while Actor is mayor.
10: putTangible(_,launch_tangible,3,3)[sai__agent(Actor)]
    count-as evacuate(industrial_zone)
    while Actor is firefighter | Actor is logistic_cell.
11: putTangible(_,launch_tangible,3,3)[sai__agent(Actor)]
    count-as support_evacuation(industrial_zone)
    while Actor is support_cell.
/* The mayor names his/her representant at the OCP when he/she
sends a message with the content 'represent_mayor_ocp' */
12: putTangible(Table,message_tangible, X, Y,From,Target,
            represent_mayor_ocp)[sai__agent(Actor)]
    count-as  name_representant_ocp
    while From is mayor.
/* The OCP is linked to mayor when the mayor's representant at
OCP sends him/her a message with the content 'crisis_report' */
13: putTangible(Table,message_tangible, X, Y,From,Target,
            crisis_report)[sai__agent(Actor)]
    count-as link_mayor_ocp
    while From is representant_ocp & Target is mayor.
/* A zone preventive phase of crisis management counts as that
zone being secure if (i) it does not pose electrical risks and
(ii) it has at most 500 inhabitants*/
14: security_phase(_,Zone,preventive) count-as secure(Zone)
    while not(AnyState is electric_risky(Zone)) &
        ((nbInhabit(_,Zone,X)&X<=500) |
         security_phase(_,Zone,preventive) is secure(Zone)).
/* A zone preventive phase of crisis management counts as that
zone being insecure if it is electrically risky */
15: security_phase(_,Zone,preventive) count-as insecure(Zone)
      while AnyState is electric_risky(Zone).
/* A zone emergency phase of crisis management always counts as
that zone being insecure */
16: security_phase(_,Zone,emergency) count-as insecure(Zone).
/* A zone is electrically risky if an actor counting as a
firefighter puts the tangible alert_tangible in
the coordinates (1,2) */
17: count-as electric_risky(downtown)
  when putTangible(_,alert_tangible,1,2)[sai__agent(Actor)]
      while Actor is firefighter.
/* The deadline to report information is 60 seconds */
18: nticks(clock,Time) count-as max_time_to_inform
      while (Time mod 60000==0).
```

5 Contributions of SAI regulation to complex crisis management issues

To illustrate SAI in practice in our crisis management application, we suppose a system composed of four tangible tables, possibly remotely placed, identified as `table_ccp`, `table_logistic_cell`, `table_support_cell`, and `table_fire_brigade`, used by the CCP, LC, SC, and FFs, respectively. The regulation of the application follows the specification illustrated in Section 4.5, unless stated otherwise.

Human actors representing the `mayor`, `logistic_cell`, `support_cell`, and `firefighter` have checked in the system, carrying then the proper agent-status functions according to the constitutive rules 1 to 4. They collaborate in two zones: the `downtown`, containing 300 inhabitants, and the industrial zone (`industrial_zone`), containing 400 inhabitants. Upon start, both zones are in the preventive phase of crisis. The following sections illustrate how SAI allows situating the regulation in front of discrepancies in the constitutive rules, inconsistencies in the norms, environmental evolutions, or increase in system autonomy.

5.1 Avoiding discrepancies in the interpretation of the environment

The different actors and organisations collaborating in crisis management may have different particular interpretations about the same fact occurring in the environment. To be effective, however, their efforts must be coordinated based on the same interpretation about each situation (i.e., on the interpretation provided by the institution 'crisis management'). Consider that, for example, for the mayor, a zone is secure whenever it is in the preventive phase and its number of inhabitants is below a certain threshold. For the FFs, conversely, a zone is secure whenever it is in the preventive phase and posing no risk, such as an electrical one. That is to say, a secure zone is differently constituted in mayor and FF perspectives. The constitution of a secure zone, according to particular views of mayor and FFs, could be expressed by the following constitutive rules:

```
/* Mayor's view */
security_phase(Zone,preventive) count-as secure(Zone)
while (nbInhabit(Zone,X)& X<500) |
       (security_phase(Zone,Phase) is secure(Zone)).

/* Firefighters' view  */
security_phase(Zone,preventive) count-as secure(Zone)
```

```
while not(electric_risky(Zone)) & Zone is preventive &
      (security_phase(Zone,Phase) is secure(Zone)).
```

In this example, as the mayor's and the FFs' conditions `nbInhabit(Zone, X)&X<500` and `not(electric_risky(Zone))` do not overlap, interpretation inconsistencies will occur, since one will consider the zone as secure while others will consider the contrary. This may lead to incoherences in the regulation of the actions as the same action can be considered as mandatory and forbidden according to the perspective of the different actors. For example, if the downtown is on the secure phase of crisis management, has 1000 inhabitants, and is not electrically risky, then FFs consider themselves as prohibited to evacuate the downtown because it is a secure zone (norm 3). For the FFs, such evacuation is up to the mayor as he/she is the one responsible for evacuating secure zones (norm 1). The mayor, on his/her turn, does not consider himself/herself as responsible for evacuating the downtown as he/she does not consider it as a secure zone (i.e., for the mayor, norm 1 is not activated). Thus, neither the mayor nor the FFs consider themselves as responsible for evacuating an endangered zone.

These inconsistencies can be solved by aggregating these two constitutive rules, generating the constitutive rule 14, which expresses the institutional conception of a secure zone, independent of the particular view from the actors about what a secure zone is.

Notice that conflicts in the interpretations may arise in real time, thus being unpredictable in design time. These cases, naturally, cannot be solved by specifying constitutive rules in design time. In this case, empowered agents (humans or artificial) could define new constitutive rules at run time.

5.2 Keeping independent normative and constitutive layers

Having norms based on the abstraction provided by the constituted status functions allows to specify the regulation considering the crisis domain independent of—but still connected to—the environment where the crisis management takes place. With this clear separation between normative and constitutive levels, the constitutive rules may change without requiring to change the norms. This is an advantage as the norms can remain stable even when the environmental elements regulated by such norms change. For example, the way by which the mayor commands evacuations could change from a tangible action to the sending of a message to the LC. To introduce this change in the scenario, we can replace the constitutive rule 6 by the one shown below, without any change in the norms related to the command of evacuation (1 and 2):

```
6: send_message(From,To,"evacuate downtown")
      [sai__agent(Actor)]
   count-as command_evacuation(downtown)
   while From is mayor & To is logistic_cell
```

The contrary is also possible: norms can be changed without changing the constitutive rules. Consider, for example, norm 3. It is stated that the `mayor` is prohibited to ask the LC and SC to evacuate a `Zone` when it is `insecure`, which means for him/her that the zone is in the emergency phase of crisis, or it poses some electrical risk, or it has more than 500 inhabitants (constitutive rules 8 to 10). The normative specification could evolve to consider electrical risk as the only condition prohibiting the mayor to command the evacuation. To reflect this evolution, the constitutive rules could remain as they are and norm 1 can be changed to

```
electric_risky(Zone): mayor prohibited
    ask_for_evacuation(Zone, logistic_cell).
```

5.3 Contextualising the set of active norms

The set of active norms (i.e., the norms that must be followed by the actors) may be different under different contexts. Situating the normative regulation following the SAI approach enables us to have such a contextualisation considering the different contexts of the environment where the collaboration takes place. This section presents two examples of such a contextualisation. Section 5.3.1 shows the active norms evolving according to the evolution of the phase of the crisis. Section 5.3.2 shows the set of active norms being defined according to the zone under security procedures.

5.3.1 Contextualising norms according to the crisis phase

Norms can evolve automatically, depending on the phase of the crisis. As already mentioned, in the preventive phase, the mayor is obliged to perform an evacuation of zones whose number of inhabitants is lower than a threshold. When the phase changes to emergency, the mayor becomes forbidden to perform evacuations and it is mandatory for the FFs to do it. In the preventive phase, the environmental property `security_phase(Zone, preventive)` always holds. If `Zone` is not electrically risky and has at most 500 inhabitants, then the status function `secure(Zone)` is constituted by the constitutive rule 14. As a consequence, norms 1 and 4 become active. When moving to the emergency phase, the previous environmental property is modified to `security_phase(Zone, emergency)` and the status function `secure(Zone)` is not constituted any more. The status function `insecure(Zone)` is now constituted according to the constitutive rule 16, which activates norms 2 and 4. As may be seen, by changing the context (from preventive to emergency), even if the environmental facts are interpreted with the same set of constitutive rules, the active norms will change.

5.3.2 Spatial contextualisation of norms

The constitution of secure and insecure zones evolves particularly according to each zone. Different zones may be in different phases of the crisis, may have different classifications regarding electrical risks, may have different numbers of inhabitants, etc. These differences require particular sets of active norms according to the zones. Basing the norms on the interpretation of the environment provided by the constitutive rules enables such spatial contextualisation of the active norms. For example, if the GIS informs the properties `security_phase(downtown, preventive)` and `security_phase(industrial_zone, emergency)`, then the downtown is considered secure while the industrial zone is considered insecure according to constitutive rules 14 and 16. As a consequence, the set of obligations and prohibitions standing for the different actors is different in the different zones.

5.4 Contextualising the normative lifecycle

Even when the set of active norms does not change, the conditions determining activations, violations, and fulfilments of the active norms can change according to the context. For example, in certain circumstances, the SC is obliged to support the LC on evacuation procedures. By constitutive rule 11, such obligation is fulfilled in the collaboration platform when the actor carrying the status function of `support_cell` puts a `launch_object` on the proper coordinates of the table. However, we could imagine more contextualised norms such that the actions performed by the SC to fulfil the obligation to `support_evacuation` are different according to the evacuated zone. For example, using a `launch_object` could mean the support for the evacuation of the downtown, while sending a weather report to the LC could mean the support for the evacuation of the industrial zone. The constitutive rule 11 could be split in two rules as follows:

```
11a: putTangible(_,launch_tangible,1,2)[sai__agent(Actor)]
       count-as support_evacuation(downtown)
       while Actor is support_cell.

11b: putTangible(Table,message_tangible,3,3,Target,
                        weather_report)[sai__agent(Actor)]
       count-as support_evacuation(industrial_zone)
       while Actor is support_cell & Target is logistic_cell.
```

This example illustrates the contextualisation of the norm fulfilments. The same idea applies to norm activations, violations, etc. For example, norms 5 and 6 are activated when an evacuation command is emitted. By constitutive rule 6, such a command is constituted by the event of the `mayor` putting a `launch_object` on the table. This constitution could be contextualised so that, for example, in certain circumstances, the command of evacuation is constituted by either (1) actions other than putting a `launch_object` or (2) the same action, triggered by actors other than the mayor.

5.5 Assigning norms independent of the actions of the assignees

Sometimes actors have some control over the agent-status function that they carry. As a consequence, they have some control over their standing obligations and prohibitions. However, the scenario may require to assign status functions to the actors even if they do not intend to do so.

For example, actors do not have obligations or prohibitions targeted to FFs unless they actively check in the table_fire_brigade (constitutive rule 4). However, an actor becomes representative_ocp—having thus new obligations—exclusively due to an action performed by the mayor (constitutive rule 5).

5.6 Designing empowerment

The notion of 'constitution' has been employed to model the institutionalised power, i.e., the power of agents to produce facts in the institution by the performance of specific kinds of actions in certain conditions (Jones and Sergot, 1996). The conditions of empowerment usually include the position occupied by the agent in the institution, which, in SAI, is captured by the agent-status functions. SAI allows us to design the institutionalised power in the crisis scenario. For example, by constitutive rule 12, an actor carrying the status function of mayor is the only one having the power, by sending a message, to make another one the representative of the mayor at OCP. The same action, performed by an agent that does not carry the status function of mayor, does not have such effect.

5.7 Increasing the system's autonomy

As mentioned in Section 2, the system may change from an application where human actors undertake all actions, to a more autonomous crisis monitoring one, where the system can be more autonomous, and automatise some actions.

Suppose that the mayor has been informed about a flood in a given zone. In this context, the mayor is obliged to produce the event status function 'ask for evacuation in X, Y'. In an application where human decision is required, the following constitutive rule would specify how the mayor can undertake the required action through a tangible interaction:

```
putTangible(_,tangibleObject1,X_zone,Y_zone,Actor)
  count-as ask_for_evacuation(Zone, logistic_cell)
  while Actor is mayor.
```

In a more autonomous crisis monitoring, on the contrary, the task 'ask for evacuation in X, Y' would be undertaken autonomously by the system if it, in some way, gets information about the crisis in the different zones. The constitutive rule is defined as follows:

```
get_information(flood, Zone, Agent)
  count-as ask_for_evacuation(Zone, logistic_cell)
  while Agent is mayor.
```

6 Related work and discussion

This paper highlights the use of situated artificial institution (SAI) within a hybrid, mixed, normative MAS to regulate human collaboration in crisis management. The proposed design draws on considerations from several research fields. We first rapidly recall the specificities of human collaboration in crisis management, and sketch some answers from the field of computer supported collaborative work (CSCW). We then show its relation to some major issues in distributed, situated, and social cognition. We finally discuss the added value of normative multi-agent design, more specifically, considering the field of SAI.

Crisis management is a complex collaborative activity where multiple actors and organisations participate, potentially distributed in time and space, with local perceptions, goals, and policies that may diverge (Oomes, 2004). They must act and coordinate under a degraded environment and critical constraints, with clear rules. The lack of mutual knowledge of these rules makes it difficult to ensure a consistent response of the rescue actors.

Current platforms often provide simple communication tools (e.g., Google Wave or Wiki) giving a response to contexts clearly defined and closely supervised. Their adaptation within a crisis management context is possible only for well defined emergency routines and is not tolerant to exceptions (Franke and Charoy, 2010). In CSCW applied in this field (Pipek *et al.*, 2014), particular attention is paid to context awareness, with a focus on the policies that guide the distributed work on sharing a common physical environment (Shaer and Hornecker, 2010). Our proposal is based on a shared physical environment and shared organisational norms. The tangible environment used supports flexible and opportunistic activities. Virtual feedbacks point out potential gaps or inconsistencies between policies, thus supporting organisational context awareness (Thévin *et al.*, 2014). A hybrid, mixed, and normative multi-agent approach is well suited to support such principles. We have also proposed several modelling spaces to cope with the physical dimension, namely production and communication, and the organisational dimension, namely coordination.

Among the different issues on norms applied to CSCW systems, such as normative design and reasoning (Ferraris and Martel, 2000; Zhang *et al.*, 2006; Oh *et al.*, 2011), we deal with the grounding of the norms within the physical environment, bridging the gap between environmental elements and the semantics of the institution (Aldewereld *et al.*, 2010).

Such an institutional situatedness has been addressed by some related work. In Dastani *et al.* (2013), it was proposed to relate environmental facts to the dynamics of the regulative elements rather than to the meaning of the institutional concepts. While it could allow to specify a tangible interaction as counting as, for example, a norm violation, it is not possible, as we do, to specify it as counting as an evacuation. Such an approach limits the desired flexibility as it is necessary to link all the norms to the environment (even those referring to the same environmental fact). For example, norms 3 and 4 in Section 4.5 refer to the same aim `evacuate(Zone)`. If these environmental facts were linked to the dynamics of these norms instead of to the concept of 'evacuation', it would be necessary to explicitly define that the same environment fact leads to the fulfilment of norm 3 and to the violation of norm 4.

Other approaches address situatedness as a problem related to interoperability between environment and institution, where interfaces observe the environment informing the regulative elements about what should happen in the institution (Campos *et al.*, 2009; Piunti *et al.*, 2010; de Brito *et al.*, 2013). The institutional meaning of the environmental facts is given by the regulative elements when they take the information provided by the interfaces. This limits the clarity of the coordination from the actors' perspective as, to know the normative consequences of the environmental facts, the actors must know how the regulative platform handles the received information.

A third approach for institutional situatedness, proposed in Aldewereld *et al.* (2010), in line with Grossi *et al.* (2006), relates environmental elements to the institutional concepts but not to the semantics of such concepts. In this case, for example, while it is possible to state that something in the environment counts as an evacuation, it is not clear whether evacuation is an event, an agent, or something else. Compared to this approach, SAI provides institutional meaning to the environmental elements relating them also to the semantics of the norms.

Fornara *et al.* (2008), Viganò and Colombetti (2007; 2008), Cardoso and Oliveira (2007), and Cliffe *et al.* (2007) consider that events occurring in the environment can count as institutional events. Compared with these works, SAI considers that environmental event states and agents can also have a meaning within the institution, and thus can also be abstracted from the concrete environment in the normative specification.

While the mentioned approaches link the elements from the environment to the norms, Okuyama *et al.* (2013) proposed 'normative places' to define the sphere of influence of the norms, providing a spacial contextualisation to the regulation. In a crisis management scenario, the different zones could be different normative places where specific norms are in effect. As shown in Section 5.3.2, SAI allows this kind of contextualisation by constituting the conditions under which the norms are active instead of linking them directly to some spatial location.

7 Conclusions and perspectives

As shown from the application examples, the proposed approach resolves the two issues encountered when designing a tool for crisis management, clear coordination (Dugdale *et al.*, 2010) and flexibility, which are necessary but may appear irreconcilable (Franke and Charoy, 2010). It allows to cope precisely with a number of issues including interpretation discrepancies, norm inconsistencies, context evolution, and level of autonomy of the system. This is easily operated thanks to the existence of two distinct modelling levels (Aldewereld *et al.*, 2010), expressed in a declarative way, by means of modifications at the constitutive or normative level. More generally, the proposed modelling brings context adaptation to the normative processing, thus approaching the flexibility–declarative compromise: changes in the physical environment will lead to the triggering of appropriate constitutive rules, which will in turn activate the corresponding norms.

Future work would involve modelling the full spaces of norms, considering the production and communication activities, thus leading to the design of situated hybrid normative-MAS for mixed interaction, in which situated organisational context awareness is the core. Quantitative analysis including different aspects of performance is also planned.

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