Validation Report of the RETURN Project Ontological Models

Bolzano Case Study - Heatwave Vulnerability in Social Housing

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Author: Cristine Griffo - Ontologist - Senior Researcher
EURAC Research

Contents

Executive Summary

This technical report presents an ontological-model validation process using a case study developed for assessing heatwave vulnerability in Bolzano, Italy. The approach combines remote sensing, microclimate modeling, socioeconomic analysis, and community engagement to create a comprehensive risk assessment framework.

Key findings indicate significant heat stress vulnerability in the Casette Inglesi social housing complex, with indoor temperatures reaching 31.3°C during summer months and concerning indoor air quality issues due to adaptive behaviors. The methodology demonstrates transferable value for urban risk assessment in similar contexts, providing a replicable framework for municipal authorities and urban planners.

1 The Case Study Casette Inglesi in Bolzano, Italy

This section is a summary of the technical report developed by (1) for the case study Casette Inglesi in Bolzano.

1.1 Background and Context

Urban heat islands pose increasing threats to vulnerable populations, particularly in social housing contexts. The RETURN project utilizes Bolzano as a testbed for developing integrated assessment methodologies that combine physical environmental monitoring with socioeconomic vulnerability analysis.

1.2 Study Objectives

- Develop multi-scale heat vulnerability assessment methodologies
- Test community participation approaches in risk assessment
- Validate integrated modeling approaches for urban heat risk
- Create transferable frameworks for urban risk management

1.3 Study Area Characteristics

The study focuses on two interconnected domains within Bolzano municipality:

- **Urban Area:** Entire municipality (52.3 km^2) for macro-scale analysis
- **Casette Inglesi:** Social housing complex (3.64 km^2) for micro-scale investigation

Figure 1: Study area map showing Bolzano municipality and Casette Inglesi district location

1.4 Methodology

1.5 Data Acquisition Framework

1.5.1 Geospatial Data Sources

- **Building Data:** Volumes, surfaces, heights from South Tirol Geocatalog
- **Topographic Data:** Digital Surface Model (DSM) and Digital Terrain Model (DTM)
- **Land Cover:** Artificial, agricultural, and forest surface classification
- **Satellite Imagery:** Landsat 8-9 OLI-TIRS (30m resolution), MODIS Terra/Aqua

1.5.2 Field Measurement Campaign

- **Portable Weather Stations:** 25 units deployed across municipality
- **Indoor Monitoring:** 12 apartments equipped with Aranet4 PRO sensors
- **Air Quality:** InBiot Mica sensors for CO_2, PM2.5, PM10 monitoring
- **Temporal Coverage:** July-September 2024 (summer campaign)

1.6 Analytical Methods

1.6.1 Surface Urban Heat Island (SUHI) Analysis

Listing 1: Pseudocode for LST processing pipeline

```
def process_suhi_analysis():
    download_landsat_modis_images(2013-2024)
    calculate_urban_morphological_indices()
    compute_biophysical_indices(ndvi, albedo)
    apply_spatial_statistics(kriging_regression, gwr)
    generate_daily_lst_estimates()
```

1.6.2 Microclimate Modeling (ENVI-met)

- **Spatial Resolution:** 5-meter (district), 1-meter (building-scale)
- **Simulation Period:** 24-hour cycle (hottest day: August 23, 2023)
- **Input Parameters:** Building materials, vegetation types, weather data
- **Output Metrics:** Air temperature, surface temperature, UTCI

1.6.3 Statistical Approaches

- Geographically Weighted Regression (GWR) for spatial heterogeneity
- Kriging interpolation for temperature surface generation
- Correlation analysis between morphological indices and LST

1.7 Results and Analysis

1.8 Urban Heat Island Characteristics

Table 1: SUHI Intensity Comparison

Season	Date	Max. LST	SUHI Int.	Corr. w/ Imperv.
Winter	14/02/2021	8.3°C	2.1°C	$R^2 = 0.67$
Summer	19/07/2022	36.7°C	5.8°C	$R^2 = 0.72$

Legend: Max. LST: Maximum Land Surface Temperature; **SUHI Int.:** Surface Urban Heat Island Intensity; **Corr. w/ Imperv.:** Correlation with Impervious Surface.

1.9 Casette Inglesi Microclimate Analysis

1.9.1 Outdoor Thermal Conditions

- **Baseline Scenario:** UTCI reduced by 3.2°C due to existing green infrastructure

- **Vegetation Contribution:** 68% of cooling effect attributed to green spaces
- **River Proximity Effect:** Additional 1.8°C UTCI reduction within 100m buffer

1.9.2 Indoor Environmental Quality

Monitoring results from 12 apartments:

- **Temperature Range:** 25.7°C - 31.3°C (mean: 28.5°C)
- **Relative Humidity:** 45% - 70% (mean: 58%)
- **CO2 Concentrations:** 600 - 2,700 ppm (exceeding 1,000 ppm in 83% of units)
- **Particulate Matter:** PM2.5 up to 110 μg/m³ (WHO guideline: 25 μg/m³)

1.10 Socioeconomic Vulnerability Assessment

Table 2: Population Vulnerability Indicators

Indicator	Value	Risk Implications
Low-income households	64%	Limited adaptive capacity
Elderly residents (65+)	22%	Higher health vulnerability
Non-Italian citizens	25.8%	Potential communication barriers
Unemployment rate	4.4%	Economic constraints

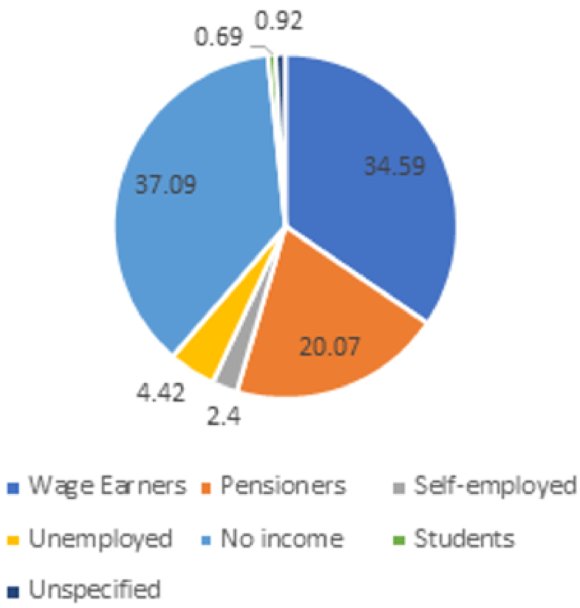

Figure 2: Percentage of tenants by employment status

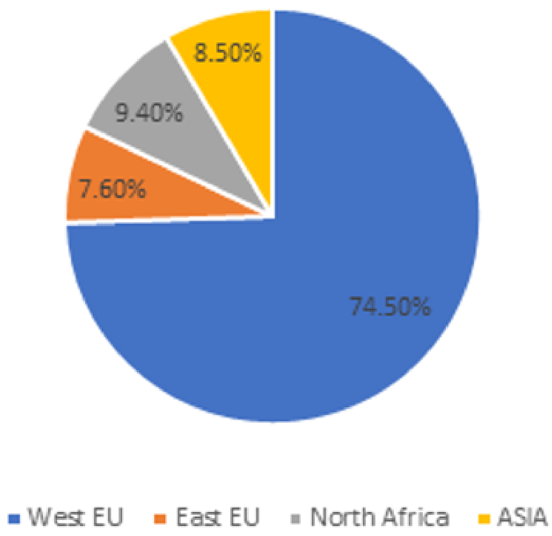

Figure 3: Percentage of tenants by geographical origin

1.11 Risk Assessment Framework

1.12 Compound Risk Storyline Development

The technical framework incorporates a multi-hazard approach:

```
Heatwave Trigger → Cascading Effects:
1. Indoor overheating → Health impacts
2. Window-closing behavior → Indoor air quality deterioration
3. Power demand surge → Blackout risks
4. Building material stress → Structural degradation
```

1.13 Impact Chain Analysis

Primary Impacts:

- Heat-related morbidity/mortality
- Indoor air quality-related health effects
- Infrastructure service disruptions

Secondary Impacts:

- Emergency response limitations
- Economic productivity losses
- Social service strain

1.14 Quantification Methodology

1.14.1 Health Impact Metrics

- **Disability Adjusted Life Years (DALYs):** Integrated mortality and morbidity
- **Heat Stress Index:** UTCI-based exposure assessment
- **Vulnerability Weighting:** Age, health status, socioeconomic factors

1.14.2 Building Performance Indicators

- **Heat Dissipation Capacity:** Material thermal properties
- **Adaptive Potential:** Retrofit feasibility scores
- **Occupant Protection:** Shading effectiveness indices

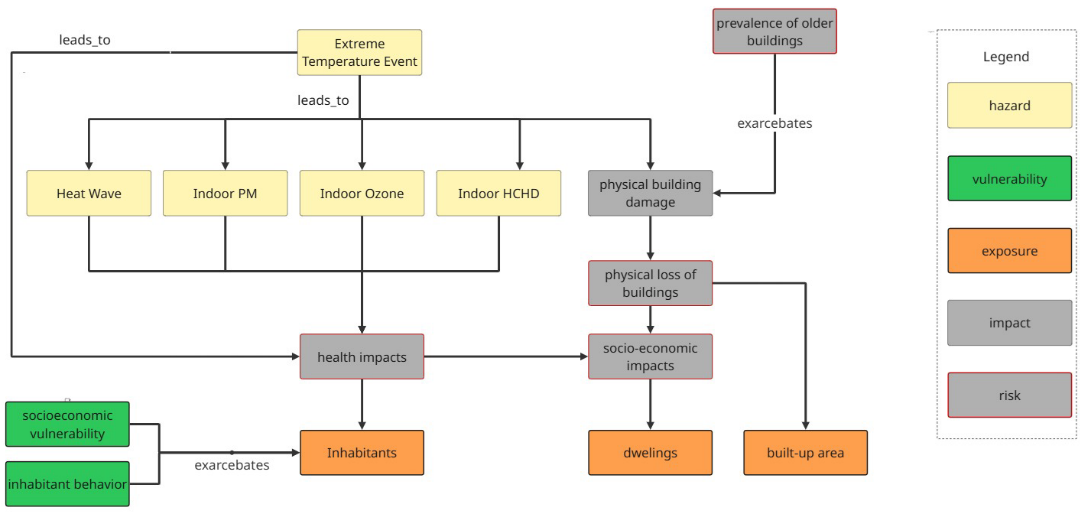

Figure 4: Impact chains showing interrelationships between hazards, exposures, and vulnerabilities

1.15 Mitigation and Adaptation Strategies

1.16 Nature-Based Solutions Assessment

Table 3: Intervention Effectiveness Comparison

Intervention	UTCI Red.	Imp. Cost	Maint. Req.
Green walls (southern exposure)	2.8°C	Medium	High
Increased tree canopy	3.2°C	Low	Medium
Permeable pavements	1.4°C	High	Low
Water features	1.8°C	High	High

Legend: UTCI Red.: Reduction in Universal Thermal Climate Index (in °C); **Imp. Cost:** Implementation Cost; **Maint. Req.:** Maintenance Requirements.

1.17 Building-Level Interventions

- **Passive Cooling:** Enhanced night ventilation protocols
- **Shading Systems:** External blinds and vegetated facades
- **Insulation Improvements:** Roof and wall retrofits
- **Behavioral Adaptations:** Occupant education programs

Figure 5: ENVI-met simulation results showing temperature reduction with green walls

1.18 Conclusions and Recommendations

1.19 Technical Validation

The integrated methodology successfully demonstrates:

- Cross-scale analysis capability (municipal to building level)
- Multi-disciplinary data integration feasibility
- Community engagement integration in technical assessment

1.20 Policy Implications

1. **Social Housing Standards:** Update design guidelines for heat resilience
2. **Emergency Planning:** Incorporate compound risk scenarios
3. **Monitoring Infrastructure:** Establish permanent sensor networks
4. **Community Preparedness:** Develop targeted awareness programs

1.21 Methodological Transferability

The framework presents scalable characteristics for application in similar urban contexts, with modular components adaptable to local data availability and risk priorities.

1.22 Future Research Directions

- Long-term monitoring of intervention effectiveness
- Integration of climate change projections
- Development of real-time risk assessment tools
- Expansion to other hazard types (flooding, earthquakes)

2 Instantiation of a real case: Heatwave in Bolzano, Italy

The case study established the municipality of Bolzano, Italy, as an open-air laboratory to test integrated approaches for multi-risk assessment, with a specific focus on heatwave-related hazards.

2.1 Motivation

The increasing frequency and intensity of heatwaves, attributable to various factors, including climate change, pose a significant threat to urban populations, exacerbating existing socio-economic vulnerabilities. The focal point of this study is the "Casette Inglesi" neighborhood, which is located within the Don Bosco district of Bolzano. The neighborhood is characterized by its status as a social housing district.

2.2 Methodology and Preliminary Findings

Casette Inglesi neighborhood: Micro-Scale and Socio-Economic Analysis

- This district (234 households, 543 residents) was selected due to its diverse, vulnerable population and aged building stock.
- Indoor Environmental Monitoring: Sensors deployed in 12 apartments during summer 2024 recorded critical indoor conditions: average temperatures of 28.5°C (peaking at 31.3°C), CO_2 levels up to 2700 ppm, and PM2.5/PM10 concentrations reaching 110 µg/m^3. Data indicates adaptive behaviors (window closure during daytime) that reduce heat gain but severely degrade indoor air quality.
- Socio-Economic Integration: Census data and participatory methods (questionnaires, semi-structured interviews) were used to characterize community vulnerability. The population includes a high proportion of low-income families, elderly, and migrants, impacting both their exposure and capacity to cope with extreme heat events.

The study moved beyond single-hazard analysis by developing a compound heatwave multi-hazard storyline. Figure **??** illustrates the cascading effects of an extreme temperature event, focusing specifically on indoor environments and their inhabitants. The figure integrates the concepts represented in the pattern shown in Figures **??** and **??**.

The impact chain begins with the extreme temperature event (categorized as a *hazard*), which leads to additional hazards. The extreme temperature event leads to heatwaves and increased outdoor ozone formation, which can infiltrate homes. This is a direct secondary hazard. Meanwhile, increased temperatures lead to indoor formaldehyde (HCHD), representing the entrapment of indoor air pollutants, such as VOCs. Health risks (mortality and morbidity) are linked to certain vulnerabilities, such as inhabitant behavior and socioeconomic vulnerability. This implies that adaptive behaviors, such as closing windows to keep heat out, can create a new hazard by trapping pollutants indoors (e.g., indoor particulate matter (PM)). The result is inhabitants become exposed. On the other hand, physical building damage is increased by the prevalence of older buildings. This damage leads to the loss of buildings, resulting in socio-economic impacts and leaving dwelling and built-up areas exposed.

2.3 Instantiation of the ontological models

The instantiation of an ontological model is defined as the process of creating specific, concrete examples (instances) based on the abstract structure and rules defined by the ontology. The objective of instantiation is to validate the designed models with a real case study. Instantiation, therefore, denotes the process of populating this empty framework with concrete data points, wherein each object constitutes an instance of a class and is assigned specific values for its properties. This process thereby asserts a fact about the real world or a particular scenario within that domain.

In the ORDUS ontology classes, such as *Exposed Urban System, City, District, Neighboorhood, Residential Building, Resident Population, Resident Person* are conceptualized, relationships: *composed_of, specializes, inheres_in, affects, leads_to, participates, manifests_in*, and both intrinsic and relational properties (e.g., health, age, vulnerability). The instantiation of this model involves creating individual instances such as an city named:: *Bolzano* composed_of:: *Don Bosco District*, which is *composed_of* a neighborhood called *Casette Inglesi*. Figures 6 and 7 shows the instantiation for the Ontology of Urban Systems, Ontology of Population, Ontology of Agents, Ontology of Urban Infrastructure. Figure 7 generalizes the 234 households and 543 residents for space reasons.

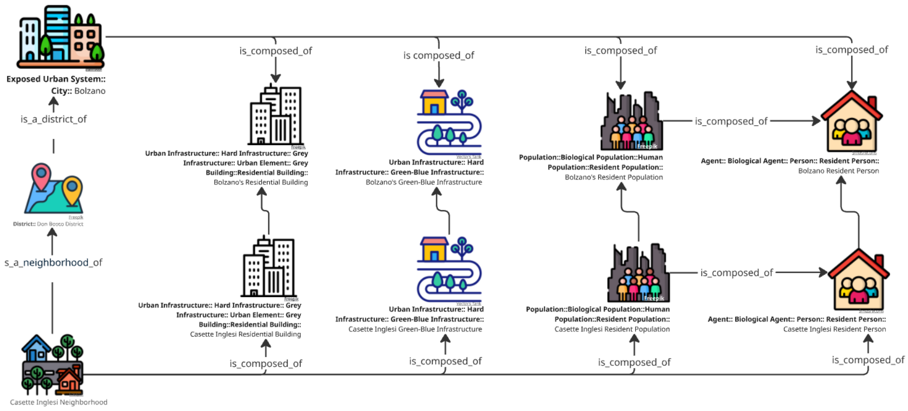

Figure 6: Instantiation Casette Inglesi Neighborhood

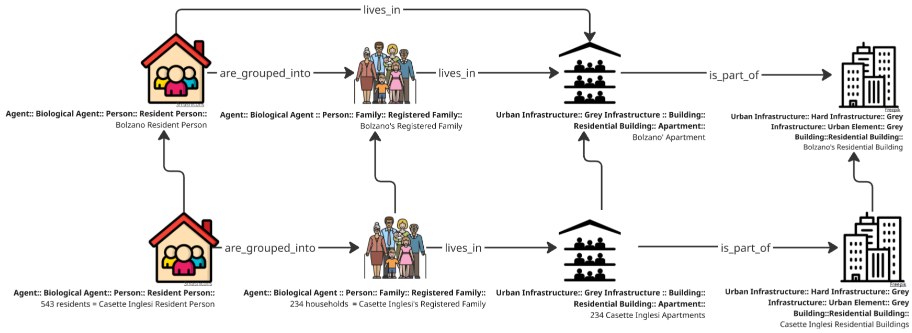

Figure 7: Instantiation Casette Inglesi Neighborhood residents

Figure 8 presents the instantiation of Person's intrinsic properties modeled in the Ontology of Agents. The population of the Casette Inglesi neighborhood is comprised of 543 individuals, 300 of whom are female and 243 of whom are male. Moreover, 31 respondents out of 543 residents completed the survey. The sample included 13 females and 18 males.

Regarding age groups, the case study did not consider the age ranges used by ISTAT[1] to define the elderly (over 64 years old) and adults (18 to 64 years old). Since the ontology of agents uses ISTAT definitions for age group definitions, this property cannot be instantiated. Similarly, no data on comorbidity were found in the case study among residents or in the sample of residents who responded to the questionnaire, which is why the *Health* quality was not instantiated.

[1] www.istat.it/it/files/2023/12/CENSIMENTOEDINAMICADEMOGRAFICA2022.pdf

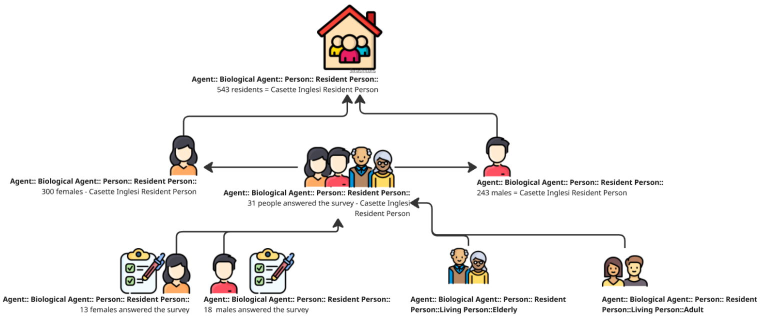

Figure 8: Instantiation Casette Inglesi Neighborhood male and female residents

The instantiation of the Risk-Driven Ontology of Urban Systems is presented schematically in Figure 9. It is important to note that, according to the findings of the case study conducted by domain experts, no data was collected and no standards were referenced that established connections with impact values, risk values, responses (mitigation or adaptation) to identified impacts, probability, severity of risks and their impacts, or the identification of the Risk Driver that initiates the chain of hazardous events and the identification of value assigners. Consequently, these classes were not instantiated. Figure 9 is described as follow:

The city of Bolzano is composed of districts, which in turn are composed of neighborhoods. Casette Inglesi is a neighborhood that is part of the Don Bosco district in Bolzano. The city of Bolzano was exposed to very high temperatures in July and August 2024. The 12 apartments in the neighborhood—as parts—are also exposed to hazardous events. Similarly, the human element, i.e., the 31 residents of the neighborhood who participated in the study. The vulnerabilities of both the structural and urban elements of Bolzano were manifested in the hazardous events and in the event that triggered these events (risk driver). The "extreme temperatures" event (risk driver) led to a series of hazardous events: heatwaves and events inside the apartments: indoor PM, indoor O3, indoor HCHO. In turn, these hazardous events led to risk situations, such as risks to residents' health and risks to buildings. These risk situations were directly influenced by the vulnerabilities of both the structural and human elements (e.g., residents' behavior and socioeconomic vulnerability). Finally, risk situations lead to socioeconomic impacts on residents and damage or loss to buildings in the neighborhood.

To obtain the case study figures at an increased scale, please utilize the link provided herein `https://miro.com/app/live-embed/uXjVL7kLSqo=/?embedMode=view_only_without_ui&moveToViewport=-2527%2C1264%2C2374%2C1237&embedId=538303189936`

3 Discussion

In the sub-ontology of systems, the aim was to define urban systems as a human-made system placed in a specific space and time. We decided to use the terminology *artificial systems* or *human-made systems* and *natural systems* instead of physical and biological systems as mentioned in (2) to emphasize the nature of the systems. At first, there was

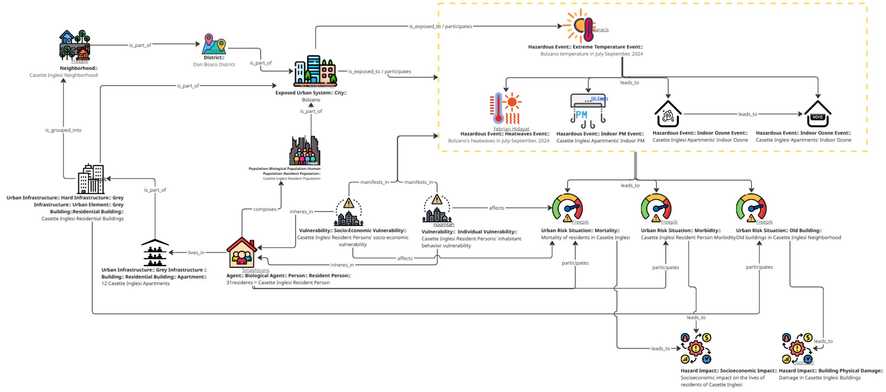

Figure 9: Instantiation Casette Inglesi Neighborhood - multi-hazards lead to multi-risks. Use this link to zoom in the figure

no need to delve into the definition of a system, but only to ratify Bunge's phrase[2]. A second design decision was, by adopting the IPCC definition of risk, only urban systems that are vulnerable and exposed to hazardous events are at risk. For this reason, we have narrowed the definition of urban system to exposed urban systems, as there may be urban systems that are vulnerable but not exposed to hazardous events, or urban systems that are not vulnerable but are exposed to hazardous events.

The service reference ontology proposed by (3) was the basis for building the use case and the ontology of soft infrastructure. With this, it will be possible to further include a representation of service contracts, for instance, reusing ontologies of service contracts available in the literature - as proposed by (4), which can later be reused in the context of the other Return project's work packages.

In contrast to the Climate System Ontology (CSO) proposed in (5), which conceptualizes *risk as "(...) dispositions of an Extreme Climate Event"*, the representation presented here emphasizes the dynamics of risk, categorizing *risk as a situation*. The urban system's vulnerabilities are activated (or manifested) by a hazardous event (e.g., large volumes of rain in a few days) and are related to the urban system's exposure to hazardous events.

It was also decided that the terms "hazard" and "exposure" would be used as object qualifications and object associations, which differs from diverse models such as the model proposed in (6). This decision was made to maintain consistency with how these terms are used in climate change communities. Another modeling decision was to emphasize the dynamic nature of things rather than their structural nature. This decision was made while considering some relevant works in this domain, such as the ontological analysis proposed by Adamo(7).

Regarding the Bolzano case study (8), used to validate the ontologies, it was observed that there were definitions that did not have instances in this specific case study and *vice versa*. It was verified in Section Future Work that the responses to the risk impacts are in progress. In addition, sensors were used and data collected for the case study. However, no sensor ontology was developed for the Return project. There are some well-established ontologies in the literature, such as the Sensor, Observation, Sample, and

[2] *the world is made of systems* apud (2)

Actuator (SOSA)(9), (10), which will be studied for future reuse and integration with the models developed.

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