Open Territory

by

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AUTHOR DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

Territory, as an incipient design setting, is progressively displacing conventional notions of site within design research and practice, and, with this, the design professions are increasingly exploring their agency as instruments of territorial intervention, formation and reformation; a disciplinary shift witnessed in recent discourses such as Landscape Urbanism, Ecological Urbanism, and Ecological Design. With this renewed contextual perspective, complexity is acknowledged as a base condition, accompanied by an operative shift toward geographical contexts, techniques, and representations which foreground systems-oriented perspectives with process-driven approaches. Similarly, a pivotal shift in focus from the essence of objects to the management of dynamic spatial systems is increasingly taking root.

Yet, the specific methods, tools and techniques used to operate within this expanding field of practice are deserving of further exploration in their own right, and it is this point that serves as the primary motivation for this thesis. As such, the thesis proposes a methodological framework which operates at the intersection of territorial design research and computational thinking, proposing the use of methods, techniques and tools drawn from spatial data mining, machine learning, and computational modelling as mechanisms for dealing with complexity in territorial systems.

The driving motivation in the development of this framework is to eliminate the gap between contextual analysis and the development of a design response, by exploring ways in which the data which is used to characterize a design context can be carried directly through to inform a design process. The framework, offered as a black-box system, is examined by way of a specific implementation, using historical data from the 2011 Japan Earthquake and Tsunami as the basis for a design experiment.

After exploring each phase of the framework – Discovery, Modelling, Formation & Exploration – the challenges and limitations of appropriating extra-disciplinary devices, and the role of subjectivity in computational modelling are discussed. Lastly, looking forward, a recursive implementation of the proposed framework is proposed as an avenue for future research and development.

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DEDICATION

For Jenny, Jakob, Maya & Ethan (a.k.a. The Dolphin).

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COMPLEX TERRITORY

An overlap of disciplinary perspectives has surfaced in recent discourses surrounding architecture, landscape architecture, and urban design, with each exploring its agency as an instrument of territorial intervention, formation and reformation. Where each design profession was once constrained to a respective focus and scale of interest, a dissolution of disciplinary boundaries has begun with the recognition that such scales are innately interrelated within complex territorial systems, intertwined within a vast set of environmental, social, political, and economic resources and constraints. Within this practice, referred to here as *territorial design research,* conventional notions of site are displaced by a recognition that territory, as an incipient design setting, offers a renewed contextual perspective which acknowledges complexity as a base condition. Here, territory is conceived of as an epigenetic milieu which binds systems and processes across scales ranging from regional planning and priorities, to local, material, resources and constraints[1]. With this, a pivotal shift from spatial determinism to the management of dynamic spatial processes has emerged as a foundational and driving principle. Where conventional design practice positions site, defined by static spatial constraints, territory exists as a dynamic continuum[2], moving between processes of deterritorialization and territorial reformation, and it is toward cultivating this flux that many design practitioners are increasingly positioning their efforts.

Discourses such as *Landscape Urbanism* and *Ecological Urbanism* offer seminal examples of territorial design research, foregrounding a process-driven approach with a systems-oriented perspective. James Corner, describing Landscape Urbanism, suggests that it, "…attempts to create an environment that is not so much an object that has been 'designed' as it is an ecology of various systems and elements that set in motion a diverse network of interaction."[3] As exemplified in much of Corner's work, Landscape Urbanism is concerned with, "[designing] relationships between dynamic environmental processes and urban forms"[4] and points toward an, "emergent urbanism, more akin to the real complexity of cities… offering an alternative to the rigid mechanisms of centralist planning".[5]

Similarly, Ecological Urbanism acknowledges the "scale and scope" of ecology, emphasizing the "dynamic relationships, both visible and invisible," that exist within and beyond urban space.[6] Ecological Urbanism emphasizes the complexity of contemporary challenges which surround urbanization, such as climate change, population growth, and resource management.[7] Acknowledging that these issues span economic, political, social, and cultural realms within an urban context, Mohsen Mostafavi suggests that a similarly "complex range of perspectives and responses" is required to expand the status quo in urban design.[8] Recognizing the limited faculty with which individual disciplines might respond to these challenges, Mostafavi endorses Ecological Urbanism as a "transdiciplinary" approach which offers a "fertile means" by which designers might address this host of concerns facing urban environments.[9]

In a similar vein, proposing that a more rigorous understanding of the discipline of ecology be utilized, Pickett et al. suggest that urban design be considered through the lens of ecological science, positioning "the urban as ecosystem."[10] Where Ecological Urbanism aims to "incorporate and accommodate the inherent conflictual conditions between ecology and urbanism,"[11] Pickett suggests that a more thoughtful consideration of ecology as a term and a discipline recognizes that, beyond a metaphorical relationship, urban environments *are* ecosystems.[12] From this perspective, ecology is situated as a systems-oriented discipline, within which, "components only have significance in the context of [their] interactions."[13] As such, an ecosystem is comprised of "a specified area or volume of the Earth, in which [a] collection of organisms and the physical environment interact."[14] Similarly, from such a systems-oriented perspective, an urban ecosystem might be considered to consist of "a biological component, a social component, a physical component, and a built component," each of which is, too, a complex assemblage of sub-systems which are inherently interrelated.[15]

Discussing systems-oriented planning and design, as it has evolved since its appearance in the early to mid-20th century, Batty and Marshall also refer to ecology in their conceptualization of urban systems.[16] Batty and Marshall use the distinction between an organism and an ecosystem to qualify the concept of equilibrium within complex systems. Here, an organism is described as "finite", and "stable in function", and thereby, in equilibrium.[17] In contrast, an ecosystem is described as "indefinite", consisting of "co-evolving sub-components", and existing in a perpetual state of disequilibrium or the state called "far-from-equilibrium".[18] Where organisms develop toward knowable states and conditions, ecosystems grow exponentially, evolving along an uncertain path.

As with ecosystems, complex territorial systems, such as those which serve as the contextual basis for the work considered herein, are among those for which such uncertainty pervades. Despite the increasing efforts made to operate and design within these systems, as exemplified by the work presented above, Batty and Marshall suggest that the complexity of these systems precludes us from being able to know or understand their true extents, which poses a great challenge toward anticipating an optimal future state.[19]

Marshall expands on such "consequences of complexity", describing them as three kinds of "unknowability".[20] Firstly, Marshall identifies the "unknowability of the system as it is".[21] Here, using both cities and ecosystems as examples, Marshall points out that complex systems are not finite, and are composed of many interactive components. In the case of ecosystems, the functioning of local systems is inevitably related to that of wider, even global systems. Similarly, in the case of cities, the functioning of urban systems both affects and is affected by regional systems, and so forth. [22] In both cases, identifying the boundaries of the system becomes a difficult, if not impossible task, because there are little means by which to verify that all components have been included.

Secondly, Marshall identifies the "unknowability of effects of intervention".[23] Here, it is suggested that, even if it could be confirmed that all components of a system have been accounted for, complex systems evolve along unique trajectories, offering little by which to base a prediction on the cascading effects an intervention may have.

Lastly, Marshall identifies the "unknowability of optimal future state".[24] It follows that if one cannot predict the specific effects of an intervention, then one is faced with a significant challenge in planning an optimal future state. Yet, beyond this initial limitation, Marshall suggests that, even if prediction were possible, there is no way to know what an optimal state for a complex system would look like.[25] Returning to the distinction between an organism and an ecosystem, an optimal state for an organism might reference its fully developed, or adult form. However, in considering an ecosystem there is no such "mature form" to refer to. [26] Similarly, the evolution of an ecosystem is an indefinite process, which remains in a state of disequilibrium.

This characterization of complexity, and the consequences of operating within it, reveals uncertainty as a significant challenge which designers are faced with when intervening within complex territorial systems. By this characterization, on its own, intervening within complex territorial systems may even appear futile. Yet, underlying this complexity is a set of fundamental qualities, which upon closer inspection may shed light on how territorial design research, as a practice, might be further explored and developed. Complexity in territorial systems can, in large part, be attributed to the notion that they are *open systems*, which are *multivariate, multi-scalar, emergent, and epigenetic* in nature.

Complex territorial systems are ***open****.*
Openness, with respect to complexity, implies that a system is open to interact with an indefinite array of external forces and flows of energy, matter and information[27], ultimately, the full cast of which remains dynamic and uncertain. Openness, as such, greatly contributes to the complexity of a system, and its tendency to remain in a state of disequilibrium.

Complex territorial systems are ***multivariate****.*
Related to the idea that complex territorial systems are open is the notion that they are composed of *multivariate* components and, thereby, best understood through the consideration of multivariate perspectives.

As a core principle, "complexity" refers to "systems with many different parts."[28] For this reason, terms like multi-disciplinary, trans-disciplinary, inter-disciplinary, and pluri-disciplinary are increasingly used to describe practices which intend to confront and operate within complex systems, such as those considered herein. The distinction between these terms and the precise approach which may be best remains up for debate, but, what is recognized is that a meaningful understanding of such systems is more likely to come from an understanding of the "actions and interactions" between multivariate components, as they are organized from the bottom up, rather than by approximating a system of control which operates on them from the top down.[29]

Complex territorial systems are ***multi-scalar****.*
With the notion that complex territorial systems are composed of multivariate components, it follows that such components can exist and interact across multiple scales. This conception is particularly important in considering the cascading effects which can ripple through complex territorial systems, and suggests a need to be able to operate at multiple scales simultaneously.

Complex territorial systems are ***emergent****.*
As the previous point suggests, with the interaction of multivariate components, across multiple scales, comes a range of cascading effects, which have a tendency to drive open systems toward non-equilibrium. Among the reasons for this is that, such cascading effects can include outcomes of system interactions which exceed any sum of the systems component parts. As such, complex territorial systems can be characterized as emergent in nature.

Complex territorial systems are ***epigenetic****.*
Epigenetics typically refers to the study of how genes can be turned on or off by environmental factors, or, put another way, how the same genetic make-up can produce a range of phenotypes, depending on its context, or the force of external actions upon it.[30] With this in mind, in the context of territorial systems, the term epigenetic can used to describe how differentiated spatial outcomes might emerge from an environment as a result of external forces acting upon it.[31]

With this expanded characterization of complexity in territorial systems in mind, strategies for evolving the practices utilized within territorial design research can be identified, specifically looking to increase the effectiveness of these approaches. The above mentioned work, drawn from a range of systems oriented, process-driven discourses which acknowledge complexity as a base condition, reveal an operative shift toward geographical contexts, techniques, and representations, where "maps, vectors and environments" supplant "plans, sections and spaces" as the basis for an alternate framework for design research.[32] Yet, the specific methods, tools and techniques used to operate within these complex contexts are deserving of further exploration in their own right, and it is this point that serves as the primary motivation for this thesis.

The work that follows begins by identifying the site of such exploration as the intersection between *territorial design research* and *computational thinking* in chapter 1.2, and then goes on to propose a methodological framework for operating at this intersection in chapter 1.3.

Part 2 of this work entails a design experiment focused on exploring a range of computational methods, techniques and tools which operate within the proposed methodological framework, using the 2011 Japan earthquake and tsunami as a case context. An important consideration in Part 2 of this work is that *design* in this context is not applied in a traditional sense and takes on a somewhat unconventional connotation, embracing an ideological shift in attention from the essence of objects to the behaviour of systems. Moreover, working in the domain of *territorial computation*, activities associated with design are expanded to include those which are traditionally rooted in external disciplines of computation, such as data organization, formatting, processing, and modelling, as well as algorithmic design and implementation.

Given the expansive scope of this exploration, it is not surprising that many limits are hit, both technical and conceptual, throughout the course of the work. With this in mind, the exploration was conducted in such a way that limits, particularly resulting from skill-based, and time-based constraints, were circumvented to facilitate a prototypical cycling through the proposed framework. These limitations, and the strategies employed to circumvent them, along with other themes emerging form the exploration are presented in Part 3.

TERRITORIAL DESIGN RESEARCH & COMPUTATIONAL THINKING

"Computational thinking is using abstraction and decomposition when attacking a large complex task or designing a large complex system. It is separation of concerns. It is choosing an appropriate representation for a problem or modelling the relevant aspects of a problem to make it tractable. It is using invariants to describe a system's behaviour succinctly and declaratively. It is having the confidence we can safely use, modify, and influence a large complex system without understanding its every detail."[33]

Contemporary architectural attempts to address complex territorial systems depend on the "discovery, interpretation and presentation of multivariate spatial patterns"[34] and, to this end, mapping is often a principle mechanism by which territorial potentials are explored. Beyond the "physical attributes of terrain [such as] topography, rivers, roads, [and] buildings", mapping can engage "natural processes, such as wind and sun; historical events and local stories; economic and legislative conditions; even political interests, regulatory mechanisms and programmatic structures."[35] The capacity of mapping to render such forces and interrelationships visible enables an understanding of the "social and natural processes" by which territory is comprised.[36] As Corner indicates, mapping, "...unfolds potential; it remakes territory over and over again, each time with new and diverse consequences."[37] Beyond offering a simple representation of possibilities, mapping is "subjectively constituted",[38] and an "application of judgment"[39] capable of "actualizing"[40] territorial potential. As such, mapping attempts to simulate epigenetic territorial possibilities, and, as a practice, becomes an iterative process of de-territorialization and re-territorialization.[41]

Mapping, as a creative activity, offers a shift from an authoritarian application of predetermined typologies to a "process of exploration, discovery and enablement"[42] of potentials within a set of contextual resources and constraints. More than the practice of mapping itself, it is this conceptual shift that represents a pivotal thread common to the design research considered herein. While integral to a distinction between mapping and planning, this *process of exploration, discovery and enablement* also points to an operative mode of *computational thinking*, implicitly embedded within much work aligned with territorial design research, as described above.

Formally, computational thinking refers to, "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent."[43] Under this definition, the "information processing agent" can be either human, machine, or, more typically, a combination of the two. [44] Yet, beyond the specifics of the "information processing agent", of foremost importance is the implied mental activity which drives this process. At its highest level, computational thinking is a process of abstraction which allows complex problems to be broken down into manageable components that can be addressed individually, while collectively addressing the larger problem at hand. Utilizing abstraction, computational thinking "gives us the power to scale and deal with complexity," which is likely why it is increasingly utilized by a broad range of disciplines tasked with dealing with complex problems. The result is a cast of emerging sub-disciplines such as computational ecology, computational economics and computational social science.[45]

Mapping, as Corner describes it, is a process of abstraction, consistent with this description of computational thinking; a notion which is particularly well supported by the "operational structure" of mapping which he lays out.[46] In this regard, Corner offers a deliberate framework for dealing with the complexity which mapping must grapple with, by suggesting that the activity be structured as "fields", "extracts" and "plottings."; each a unique mechanism for abstraction.[47]

Using Corner's definition, the field is "the paper on the table itself".[48] The field establishes the "graphic system", such as the "frame, orientation, coordinates, scale, units of measure and… graphic projection" which will host the extracts of the following phase.[49]

Ultimately, the field operates as an abstraction of "the actual ground", and sets the stage for the remainder of the process. [50]

Extracts are the components of the system which are observed and deemed relevant to the design problem at hand. As such, extracts are abstractions of territorial components which are "isolated… from their original seamlessness with other things", and thereby "de-territorialized", as they are laid out on the field."[51] Extracts can include both physical objects and informational data, such as, "quantities, velocities, forces, [and] trajectories."[52]

Finally, plotting involves a "drawing out" of "new and latent relationships that can be seen amongst the extracts within the field." [53] Effectively, plotting entails a "re-territorialization" of sites, through a subjective re-interpretation of relationships across the field. [54]

Though Corner does not describe it as such, this process can be said to implicitly employ computational thinking, because it offers a framework for understanding and manipulating complex conditions through use of strategic abstraction. The process abstracts the actual ground by laying out the *field*, breaks down and isolates the problem by *extracting* the relevant components of the system in question, and generates potential solutions by *plotting* new relationships between those parts. As such, from a high-level perspective, Corner's operational structure of mapping can be understood as a computational framework which facilitates a process of territorial (re)formation.

The value of unpacking Corner's approach in such a way may not be immediately obvious, but, there is reason for doing so. Among the principle questions considered by this work, as established in the previous section, is, how might territorial design research evolve to better address complexity in territorial systems? With this in mind, viewing Corner's framework for mapping through the lens of computation identifies both a root mechanism for dealing with complexity, implicit within current practice, as well as an opportunity for methodological development, through the utilization of a more explicit computational approach; a strategy which is expanded in the following section.

TERRITORIAL COMPUTATION

“Simulation... is the generation by models of a real without origin or reality: a hyper-real. The territory no longer precedes the map, nor survives it. Henceforth, it is the map that precedes the territory.”[55]

As established in the previous section, and exemplified through consideration of Corner’s operational structure of mapping, inherent within recent discourses concerned with territorial design, is a process of inquiry and formation which often implicitly utilizes computational thinking, even if not intentionally set out as such. With this in mind, the question that arises is, how might such a strategy be expanded to better address complexity in territorial systems through a more explicit use of both computational thinking in establishing its structure, and computational methods, techniques and tools in carrying out its processes?

To explore this question, this thesis proposes a methodological framework which operates at the intersection of territorial design research and computational thinking, proposing the use of methods, techniques and tools drawn from spatial data mining, machine learning, and computational modelling as mechanisms for dealing with complexity in territorial systems. The framework is conceptualized as a base-unit structure, with the intention that as a single instance, it can begin by handling a small degree of complexity relevant to the territorial system under consideration, however, through recursive application, can manage greater and greater degrees of complexity.

Explicitly rooted in fundamentals of computational thinking, this strategy is based on principles of recursive abstraction, which refers to a process of system building which relies on a successive layering of abstracted components. This strategy is able to handle vast degrees of complexity because it offers the opportunity to direct focus toward one layer at a time, while gradually and collectively approaching greater degrees of overall system complexity.[56]

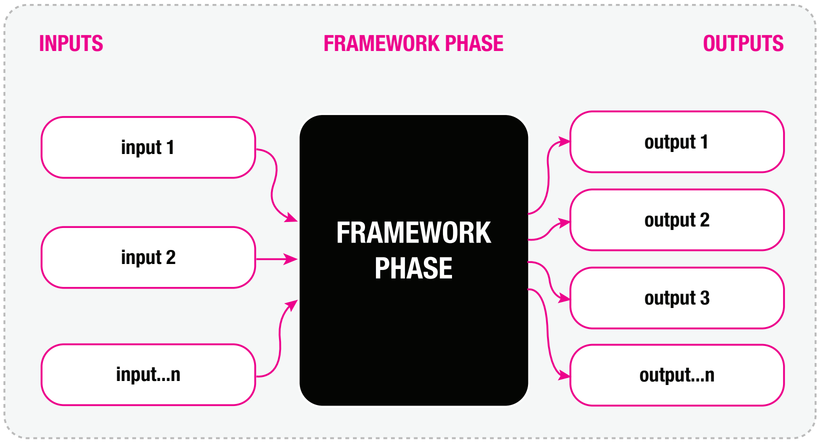


FIG. 1.3.1 Black-Box Conceptual Diagram

While, ultimately, the goal of such a research trajectory would be to implement this framework recursively (See Part 3 for an expansion on this approach), in the interest of bracketing the work within this thesis, attention is focused on a single instance implementation of the base-unit framework.

Within this scope, the base-unit framework consists of 4 phases – *Discovery, Modelling, Formation,* and *Exploration*. The framework as a whole prioritizes facilitating a direct continuity of data, as it shifts between phases. With this in mind, each phase is conceptualized as a black-box device, such that the focus for each phase is centered on its inputs and outputs, as well as interactions with adjacent phases, rather than on the specific mechanisms which are utilized to carry out its internal operations, for which a multitude of possibilities exist. The phases are broken down as follows.

DISCOVERY

The *Discovery* phase utilizes methods and techniques appropriated from spatial data mining & machine learning to **establish a characterization of territorial resources and constraints**, and the way in which such characterization occurs is a key consideration of the frameworks design.

As spatial disciplines and sciences are increasingly moving from an era which was “data-poor” to one which is “data-rich”,[57]

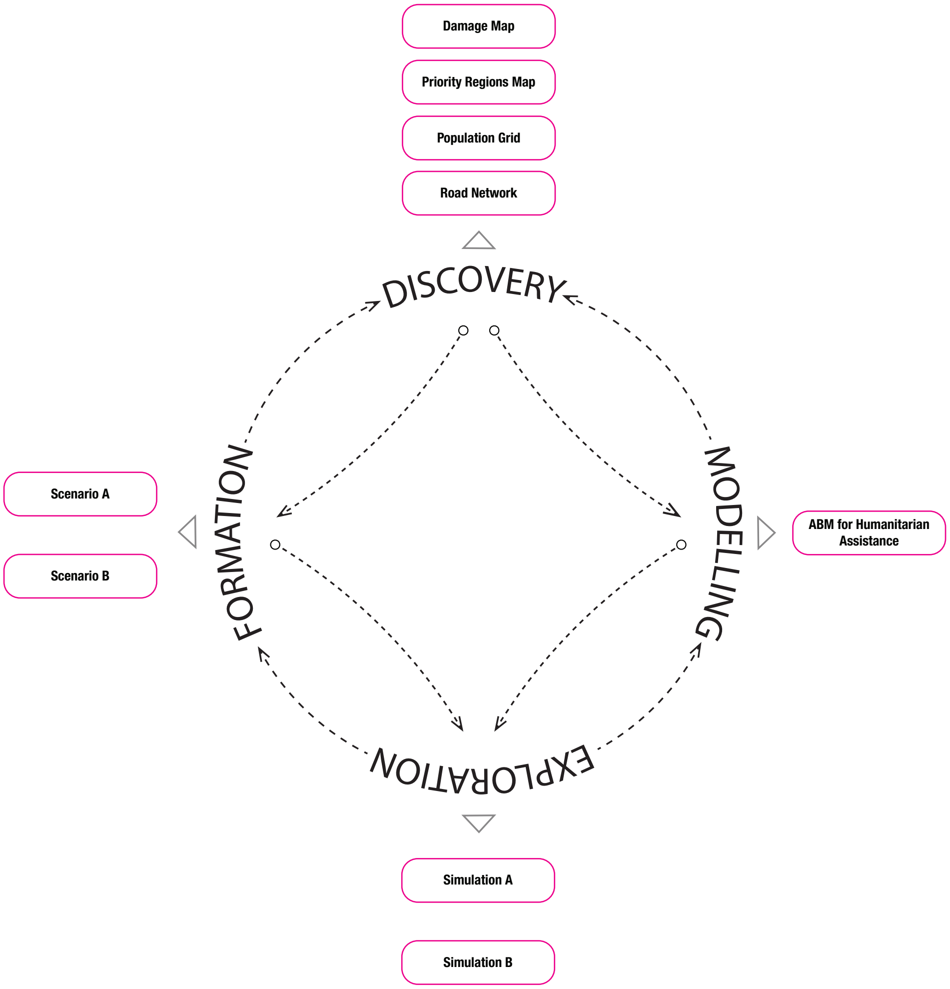


FIG. 1.3.2 Framework Conceptual Diagram

Outputs depicted at each phase are examples from the design experiment that follows (see Part 2).

data which describes the multivariate and multi-scalar conditions which characterize open, complex territorial systems abounds. Vast data resources are made available by governments, through agencies such as NASA and the USGS, as well as by international institutions such as the UN and World Bank, NGO's, Academic Institutions, and even privately held companies like Facebook and Twitter. In turn, an opportunity to gain a better understanding of complex phenomena such as urban-ecological interaction and social dynamics by analyzing such data now exists, and, with this, there has been a call to develop spatial analysis methods, techniques and tools which can extract "unknown and unexpected information" from datasets of "unprecedentedly large size (eg. Millions of observations), high dimensionality (eg. hundreds of variables) and complexity (heterogeneous data sources, space-time dynamics, multivariate connections, explicit and implicit spatial relations and interactions)."[58]

As such, spatial data mining and knowledge discovery has emerged as an active research field "focusing on the development of theory, methodology, and practice for the extraction of useful information and knowledge from massive and complex spatial databases,"[59] and it is from this field that this phase of the framework draws its methods, tools, and techniques.

Drawing from these extra-disciplinary resources, the framework supports creating a robust data environment and biases the value of maintaining this data environment as an active agent in the phases that follow.

MODELLING

Utilizing the characterization of contextual resources and constraints developed during the *discovery* phase as inputs, the *modelling* phase draws from multivariate computational modelling methods, tools, and techniques to **develop a dynamic representation of the principal relationships and interactions which comprise the territorial system** under consideration.

Such methods, tools and techniques can be drawn from a range of computational discourses tasked with dealing with complexity, such as computational social science, computational ecology, and computational economics, to name a few. The principle assumption to keep in mind is that, the model will serve as the engine behind the system simulation which drives the *exploration* phase of the framework (See *Exploration* below).

In this regard, the *modelling* phase represents a significant device for transcending the limits of mapping as described in the previous section (See Ch. 1.2), as it structures a dynamic relationship between the representation of contextual complexity established during the *discovery* phase, and the process of *formation* which drives design development, by way of simulating context-design interactions during the *exploration* phase.

FORMATION

Also utilizing the characterization of contextual resources and constraints developed during the *discovery* phase as inputs, the *formation* phase of the framework operates as **the principle forum for design decision making, and the generation of design iterations**.

As in the previous phases, the *formation* phase is open to a wide range of specific methods, techniques and tools in its specific application, which can range from manual plotting techniques, such as those that Corner describes (See Ch. 1.2), to evolutionary computational approaches.

Beyond the utilization of the products of the discovery phase as drivers of design decision making, crucial to the *formation* phase, is its relationship with the *exploration* phase; a condition which is elaborated below.

EXPLORATION

The *exploration* phase is where the products of *formation* interact directly with the products of *modelling,* by way of simulation. As such, the *exploration* phase offers **a platform for a design iteration to become**

an active component in the system model, and thereby extends **an opportunity to explore the emergent and epigenetic potentials which a design intervention may incite on its context**.

As inputs, the *exploration* phase takes design iterations, and the systems model, and as an output, it offers a simulation of design-context interactions, which can be used to explore the effects a design may have on its context, and thereby push back at the design process. As such, feedback between *formation* and *exploration* is an integral aspect of the frameworks design.

FUNDAMENTAL MOTIVATIONS AND CONSIDERATIONS IN THE FRAMEWORK DESIGN

The driving motivation in the development of this framework is to eliminate the gap between contextual analysis and the development of a design response, by exploring ways in which the data which is used to characterize a design context can be carried directly through to inform a design process.

While the phases have been presented above in a particular sequence, it is key to recognize that the framework consists of a spiraling methodology which allows feedback to occur between adjacent phases as the process progresses. For example, feedback may occur between *discovery* and *modelling* if additional contextual conditions present themselves and require characterization, as a model is being developed. Similarly, *exploration* of a design iteration may lead to greater contextual insight, and thereby stimulate subsequent work in *discovery* and *modelling*. Finally, much feedback between *formation* and *exploration* is expected, as described above.

As these cycles occur between phases, a gradual increase in system complexity is continuously developed and represented within the design process, even at a base-unit level of implementation. Similarly, with recursive application of the framework, as introduced above and discussed in Part 3, the degree to which such complexity might be expanded, represented and explored can also increase significantly.

Returning to the qualities which are attributed to complexity in territorial systems (See Ch. 1.1), as *discovery* and *modelling* are incrementally pursued, the multivariate components and multi-scalar conditions which comprise the territorial system can be increasingly represented within the framework, and, thereby, the design process. Similarly, as a greater degree of complexity is represented by the model during *exploration,* the greater the opportunity to explore and cultivate the emergent and epigenetic outcomes which a design intervention might stimulate. As such, the framework, ultimately, affords the designer an opportunity to continuously calibrate a territorial design intervention, by maintaining a direct relationship between contextual representation and design process.

The framework, presented here as a black-box system, is examined by way of a specific implementation in Part 2.

ENDNOTES

1 Sheppard, 2012, p. 179

2 Deleuze & Guattari, 1980

3 Corner, Terra Fluxus, 2006, p. 31

4 Ibid, p 24

5 Ibid, p 23

6 Mostafavi & Doherty, 2010, p. 29

7 Ibid, p.12

8 Ibid, p.13

9 Ibid, p. 29

10 Pickett, Cadenasso, & McGrath, 2013, p. 10

11 Mostafavi & Doherty, 2010, p. 17

12 Pickett, Cadenasso, & McGrath, 2013, p. 10

13 Ibid, p. 9

14 Ibid, p.9

15 Ibid, p.11

16 Batty & Marshall, 2012, p. 34

17 Ibid, p. 34

18 Ibid, p. 34

19 Ibid, p. 43

20 Marshall, 2012, p. 199

21 Ibid, p. 199

22 Ibid, p. 199

23 Ibid, p. 199

24 Ibid, p. 200

25 Ibid, p. 200

26 Ibid, p. 200

27 Tarlock, 1994

28 Batty & Marshall, 2012, p. 34

29 Ibid, p.39

30 Stevenson & Christine, 2013

31 Sheppard, 2012

32 Gissen, 2011, p. 44

33 Wing, CACM, 2006, p. 33

34 Guo, Gahegan, MacEachren, & Zhou, 2005

35 Corner, The agency of mapping: Speculation, critique and invention, 1999, p. 214

36 Ibid, p. 214

37 Ibid, p. 213

38 Ibid, p. 223

39 Ibid, p. 223

40 Ibid, p. 225

41 Ibid, p. 230

42 Ibid, p. 225

43 Wing, Research Notebook: Computational Thinking—What and Why?, p. 1

44 Ibid, p. 1

45 Ibid, p. 2

46 Corner, The agency of mapping: Speculation, critique and invention, 1999, p. 229

47 Ibid, p. 229

48 Ibid, p. 229

49 Ibid, p. 229

50 Ibid, p. 229

51 Ibid, p. 230

52 Ibid, p. 230

53 Ibid, p. 230

54 Ibid, p. 230

55 Ibid, p. 222

56 Wing, Research Notebook: Computational Thinking—What and Why?, p. 1

57 Miller & Han, 2009

58 Guo & Mennis, Spatial data mining and geographic knowledge discovery—An introduction, 2009, p. 403

59 Ibid, p. 404

CONTEXT

DISASTER AND REHABILITATION AS TERRITORIAL PROCESSES

As described in the previous chapter, territory is defined by an assemblage of social, economic, environmental and political systems, the interactions of which drive a flux of territorial deformation & reformation. Within this context, disaster can be considered a catalyst of deterritorialization; a force which abruptly alters landscapes, damaging critical infrastructure and disrupting environmental, social, and economic systems.

Similarly, disaster rehabilitation might be considered a process of territorial reformation; a progression of emergency relief, transitional support and long-term reconstruction of the structures which support territorial system functionality, such as power, transportation, water and healthcare infrastructures. As such, disaster rehabilitation is a complex process which is true to the conceptualization of complex territorial systems previously introduced (See Ch. 1.1) in that it includes multivariate components, across multiple scales, with emergent effects, and epigenetic potentials.

Acknowledging that disaster rehabilitation is a significant area of research in its own right, the following design experiment attempts to appropriate discipline specific strategies, methods and tools, and utilize them within the proposed design framework. However, first, an underlying guideline for disaster rehabilitation, which is assumed by the computational model which drives much of the work that follows (see ch. 2.3), ought to be outlined in order to set the stage for the subsequent work.

The assumption held is that disaster rehabilitation efforts often operate in accordance with a *hierarchy of needs*, addressing physiological necessities, such as food, water, sanitation, and shelter, as immediate priorities. During such a period of initial relief, which typically occupies the first month following a disaster, aid distribution centers and field hospitals are established, and food, water, hygiene and shelter kits are distributed. Re-establishing a baseline of health for the people affected by the disaster remains a priority throughout this initial phase, and this is the phase of rehabilitation considered in the work that follows.

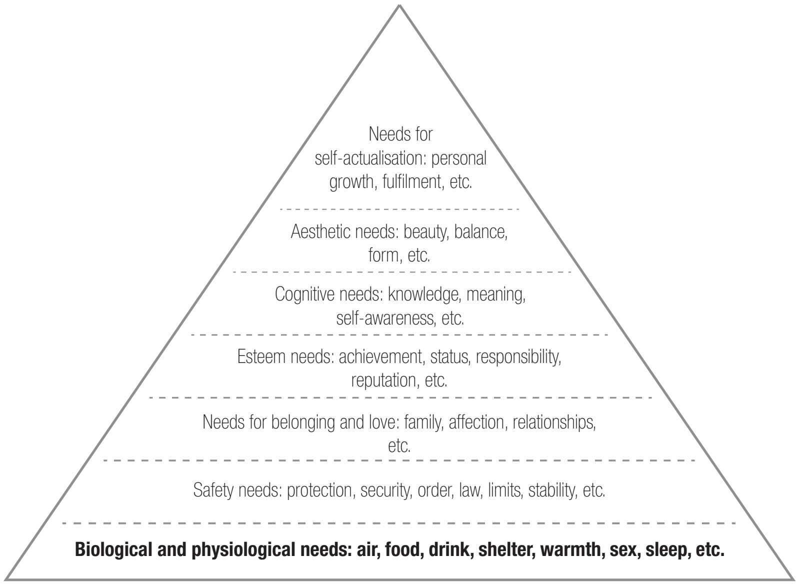


FIG. 2.1.1 Maslow's Hierarchy of Needs

EXPERIMENT DATA: THE 2011 JAPAN EARTHQUAKE AND TSUNAMI

With disaster positioned as a process of deterritorialization, and disaster rehabilitation a process of territorial reformation, this work assumes the 2011 Japan earthquake and tsunami as a historical case which offers appropriate datasets for testing and implementing the framework introduced in Part 1 of this work (see ch. 1.3).

A magnitude 8.9 earthquake struck off the east coast of Japan on March 11th, 2011, at 2:46 pm. Following the earthquake, a tsunami swept into coastal regions south of the earthquake epicenter, and inundated the plains along the coast. The Japan Port and Airport Research Institute reported 4.1m to 23.6m inundation heights at tsunami-affected ports and airports,[1] estimated damages were $122-235 Billion, and over 15000 people were reported dead or missing.[2]

It's important to acknowledge, despite the use of this data, this work does not intend or attempt to offer a holistic response to the above

FIG. 2.1.2 Earthquake and Tsunami Damage

Inundation at Sendai Airport after the March 2011 Earthquake and Tsunami

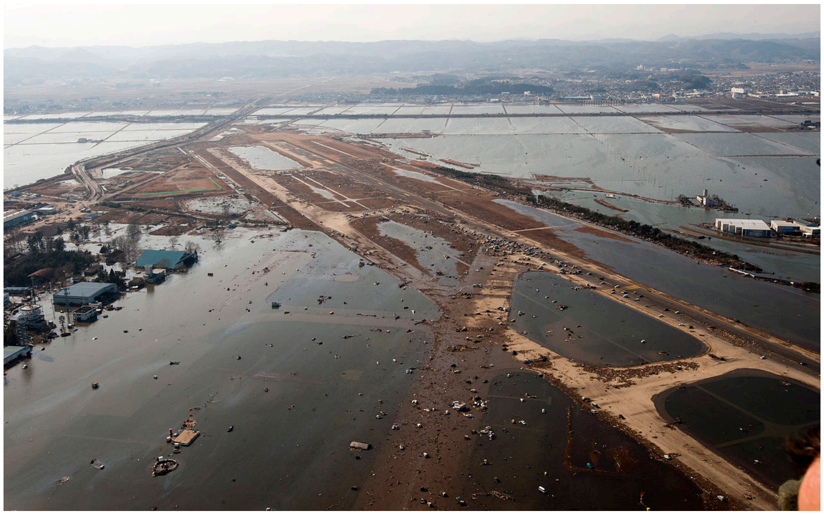


FIG. 2.1.3 Earthquake and Tsunami Damage

Damage along the northeast coast of Japan, following the 2011 earthquake and tsunami.

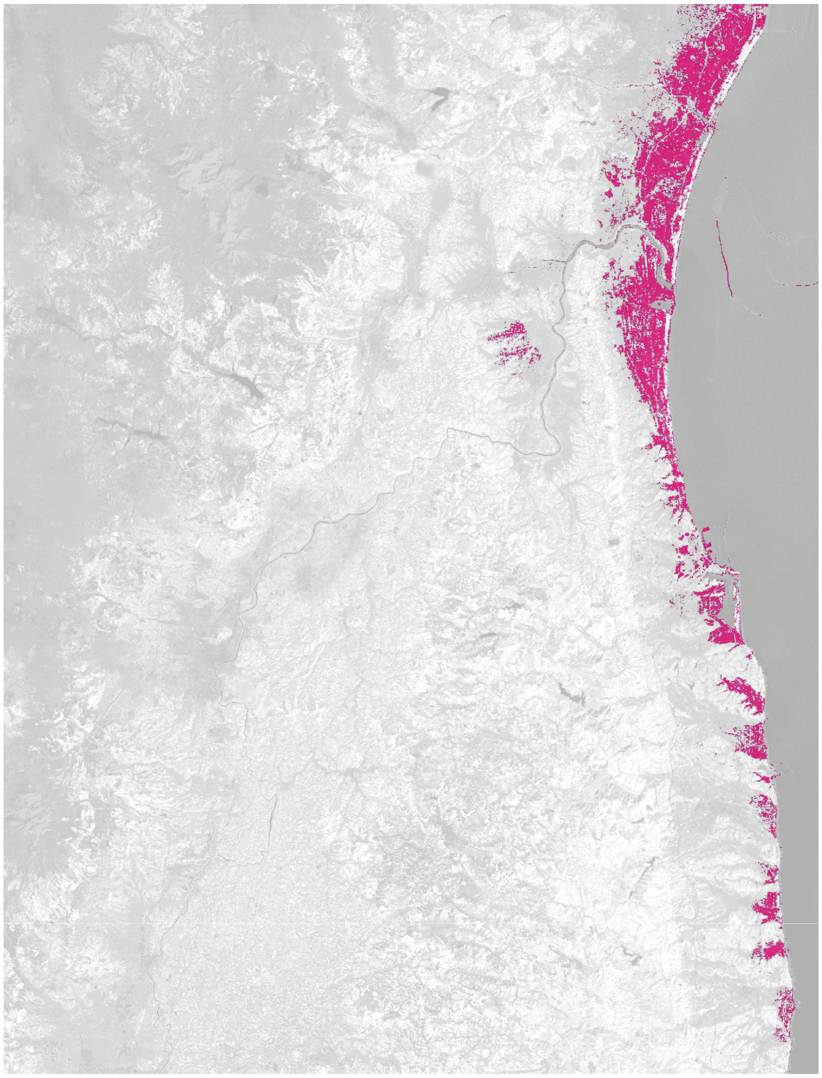


FIG. 2.1.4 Inundation Map

Inundation along the northeast coast of Japan. Refer to Ch. 2.2 for details.

mentioned crisis. Rather, data from the event is being used to develop and test the framework under consideration (see Ch. 1.3), in support of disciplinary expansion through methodological development.

Such a distinction in research strategy, emphasis and priority is critical, given that territorial design research tends to be problem-driven, rooted in contextual specifics. Yet, among the priorities of the discourse and the motivations for this work, is a desire to expand the resources with which designers might confront complex territorial systems. So, this work takes on a different nature, utilizing real-world data to stage an experimental environment in which extra-disciplinary strategies, methods and techniques may be appropriated and tested within a design context.

With this in mind, the following design experiment appropriates geo-computational strategies from recent disaster rehabilitation research, employing GIS and remote sensing, and an agent-based model (ABM), to drive an iterative process of formation within the previously introduced design framework.

REMOTE SENSING

Remote sensing can be defined as, "the measurement of object properties on the earth's surface using data acquired from aircraft and satellites."[3] As such, it measures things at a distance, without direct contact, relying on "propagated signals", such as optical, acoustic, and microwave, to transmit data. [4] Examples include imagery acquired by satellites such as Landsat, GeoEye, MODIS, and IKONOS.

Remotely sensed data, particularly that which was acquired by satellite, offers a repetitive and consistent view of the earth, which is extremely valuable in detecting and monitoring changes to the earth's surface, whether chronic or acute in nature, and whether due to natural or human activity.[5]

Offering a "big picture" view of the earth's surface, remote sensing is commonly used for environmental assessment and monitoring, agriculture, resource management, meteorology, mapping, military surveillance and reconnaissance, as well as news and media applications. With this, a wide range of remote sensing systems have been developed, offering a variety of spatial, spectral and temporal attributes, depending on a user's particular set of needs.[6] For instance, military uses often require both high resolution and frequent coverage, with little limitation associated with data size.[7] Whereas, if data is to be used to initialize or calibrate a simulation or computer model, spatial resolution may come at a cost to computational efficiency.[8]

The work that follows uses Landsat 7 ETM+ satellite imagery, acquired using the U.S. Geological Survey's (USGS) Global Visualization Viewer (GloVis)[9], as well as an ASTER Global Digital Elevation Model (GDEM), a joint product from METI/Japan Space Systems and NASA.[10] Specific usage of this data is described further in Ch. 2.2, Discovery.

GIS

In addition to remotely sensed data, the following work also uses road data acquired from OpenStreetMap[11], and population data acquired from NASA's Socioeconomic Data and Applications Centre (SEDAC).[12] To manage and process this broad range of geospatial data, QGIS, an open source Geographic Information System (GIS) is used extensively throughout the work that follows.

AGENT BASED MODELLING

Agent based models (ABMs) comprise a form of computational modelling which is increasingly being utilized to study the behaviour of complex systems, particularly those relating to both urban and geospatial studies.[13] ABMs are deemed well suited to such problems, because they operate by simulating the actions and interactions of "autonomous agents", with an aim of anticipating the effects of their collective behaviour on a system as a whole. In this context, agents are described as autonomous because they are capable of individually carrying out instructions and making decisions about their actions and interactions within a simulation.[14] As such, ABMs offer a mechanism for simulating a context from the bottom up, as they are driven by simple rules and interactions which occur between individual agents, with the key assumption in mind that, such simple behavioural rules and interactions can collectively generate complex phenomena.[15]

An ABM, developed specifically to assist in humanitarian aid plays a central role in the design experiment that follows, and is described in more detail in Ch. 2.3.

ENDNOTES

1 Port and Airport Research Institute (PARI), 2011

2 World Bank, 2011

3 Schowengerdt, 2007, p. 2

4 Ibid.

5 Ibid.

6 Ibid.

7 Ibid.

8 Ibid.

9 USGS Earth Resources Observation and Science Center (EROS), 2014)

10 Ministry of Economy, Trade, and Industry (METI) of Japan, United States National Aeronautics and Space Administration (NASA), 2014

11 OpenStreetMap, 2014

12 Socioeconomic Data and Applications Center (SEDAC); A Data Center in NASA's Earth Observing System Data and Information System (EOSDIS), hosted by CIESIN at Columbia University, 2014

13 Chen, 2012, p. 168

14 Ibid.

15 Ibid.

KNOWLEDGE DISCOVERY

DISASTER RECOGNITION: CHARACTERIZING THE DISASTER CONTEXT

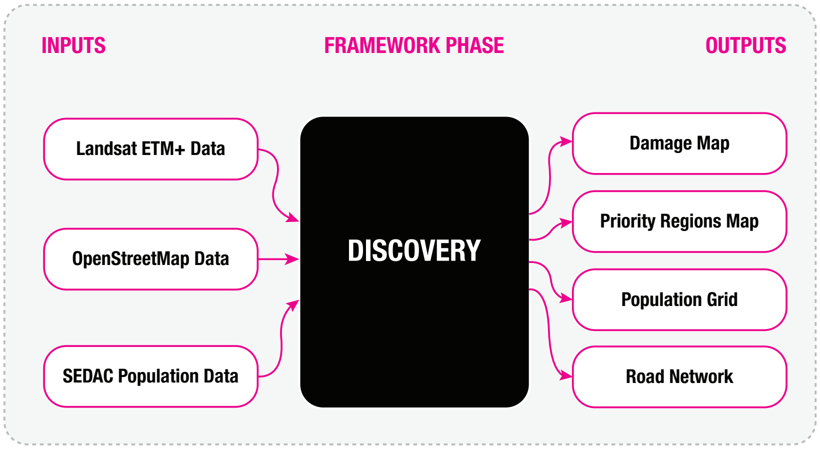


FIG. 2.2.1 Discovery Black-Box Diagram

With disaster rehabilitation positioned as a process of territorial (re) formation, the *discovery* phase of the proposed framework seeks to characterize the disaster scenario. Through preliminary context analysis, *discovery* prepares the parameters which will structure the agent based model in the following stage. With this aim, this implementation of the framework employs GIS and remote sensing tools, using sample historical data from areas along the Fukushima coast affected by the 2011 Japan earthquake and tsunami.

Specifically, the agent based model which is utilized in the following chapter, requires inputs which describe the population, transportation networks, and extent of damage to the affected area. Population and transportation data are openly available, and usable with only minor changes required to data resolution and type, however, characterizing the extent of damage to the region requires a more thoughtful approach, and thereby comprises the focus of this stage.

Here, Landsat 7 ETM+ imagery is used as a basis for mapping affected areas, using the processes, methods and techniques described

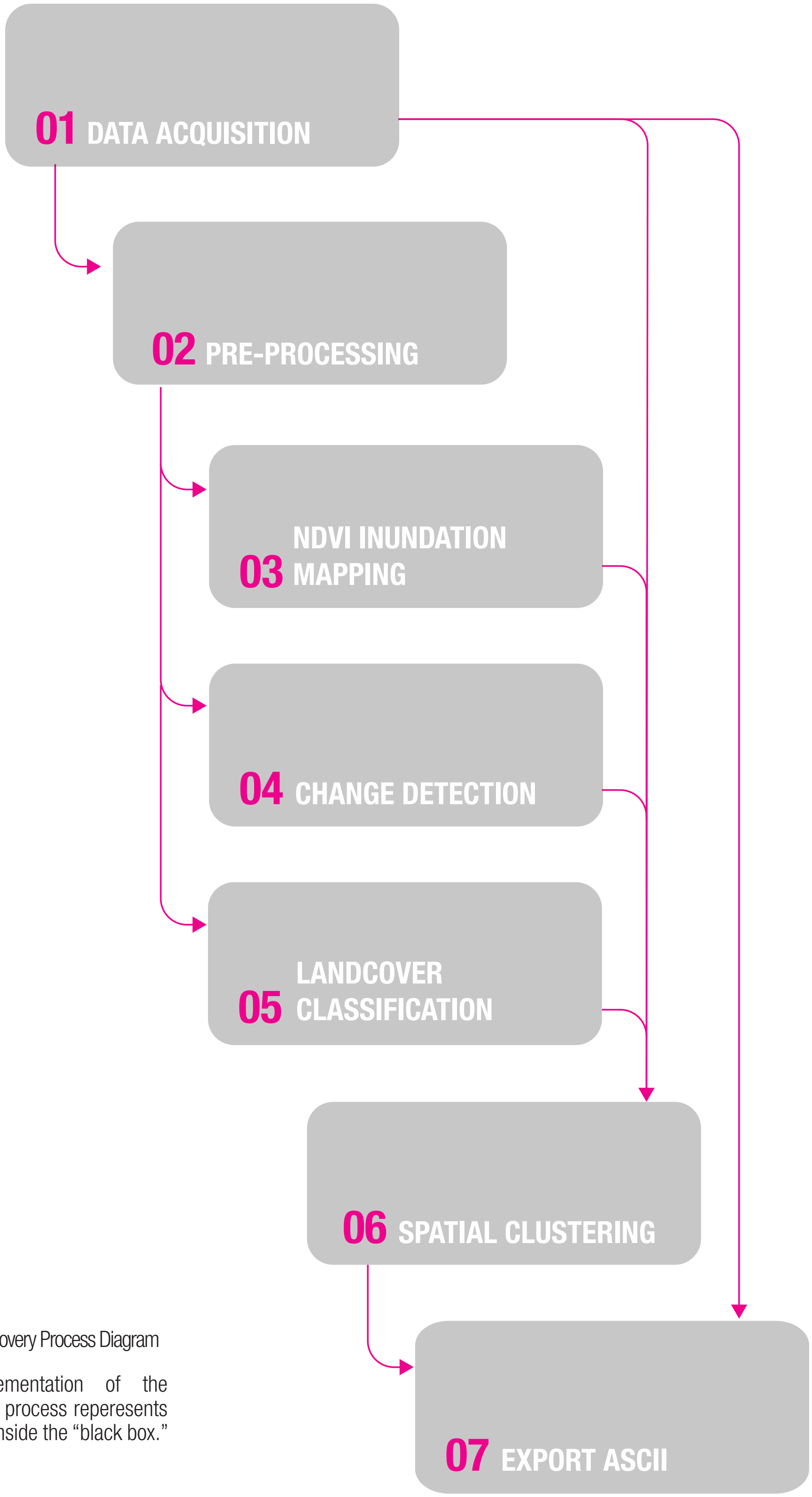


FIG. 2.2.2 Discovery Process Diagram

In this implementation of the framework, this process reperesents what happens inside the “black box.”

below to identify and depict tsunami induced regional damage.

The diagram on the opposite page presents an overview of the tactics employed in the discovery phase of the framework. Each step is then explained in more detail in the sections that follow.

DATA ACQUISITION

"Satellite images are not photographs but pictorial presentations of measured data."[1]

Multispectral sensors aboard satellite systems, such as the Landsat 7 Enhanced Thematic Mapper Plus (ETM+), detect electromagnetic radiation from a series of wavelength ranges and store them in a set of images referred to as *bands*.[2] The Landsat 7 ETM+ satellite, which is the source of the imagery used herein, detects ranges of wavelengths across the electromagnetic spectrum and stores them within 8 bands. Each band is then offered as an individual gray scale image, where each pixel of each image is a representation of the intensity of the electromagnetic radiation at that point.[3]

Separating and storing the electromagnetic spectrum like this, allows users of the data to combine the bands in various ways, offering a mechanism to create a multitude of unique colour representations. To clarify this process, consider how a digital camera works. A digital camera employs a sensor to detect red, green and blue light – the portion of the electromagnetic spectrum visible to the human eye – and then automatically combines these wavelengths to create a colour image.

In contrast, the eight Landsat 7 bands are all captured and offered individually, each representing a specific wavelength range of light, and together covering a much larger area of the electromagnetic spectrum. It is then up to the user to combine the bands in a way which captures and reflects the specific interests of their work.

Since digital devices like computer screens display images by illuminating them with red, green, and blue light, imaging software can be used to create colour images by combining Landsat bands, such that each band is associated with the appropriate *channel*. For instance, since bands 3,2 and 1 represent red, green, and blue respectively, this combination of bands will produce a colour image that appears "natural", as would be expected in a photograph. Similarly, a range of other combinations have been identified which don't appear natural, but have other strengths according to the predominant characteristics which are captured and represented by each series of bands.

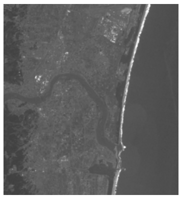
The images used in this work were acquired using the U.S. Geological Survey's (USGS) Global Visualization Viewer (GloVis).[4] The images are Landsat-7 ETM+, acquired from Path/Row: 107/34, for 24 February, 2011 & 12 March, 2011, before and after the earthquake and tsunami.

In addition to Landsat 7 ETM+, data acquired from the ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) is also used in the work that follows. The ASTER GDEM is a data product jointly produced by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA),[5] and made freely available to the public via electronic download.[6]

The ASTER GDEM is a digital elevation model which covers the entire land surface of the earth, at a spatial resolution of 15 m.[7] ASTER GDEM data is offered in GeoTIFF format with geographic latitude and longitude coordinates, and is referenced to the WGS84/EGM96 geoid.[8] As such, ASTER GDEM data is easily visualized and manipulated using GIS software, such as QGIS, as demonstrated in the work that follows.

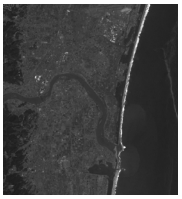
ASTER GDEM digital elevation data is easily accessed and suitable for use within a broad range of spatial analysis applications and, as such, is a widely used remote sensing resource. In the work that follows, ASTER GDEM data is used to calibrate a process of Landsat 7 ETM+ based inundation mapping, by limiting results to that which falls within a range of suitable elevations.

FIG. 2.2.3 Landsat 7 ETM+ Band Descriptions



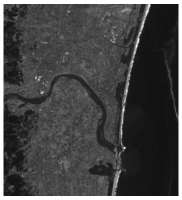
Band 1: Blue (Wavelength: 0.45-0.52)

This band has a short wavelength of light which penetrates well, and is useful for monitoring aquatic ecosystems, bathymetric mapping, and distinguishing soil from vegetation and deciduous from coniferous vegetation. This band is susceptible to atmospheric scatter, so it is also the “noisiest” of bands.



Band 2: Green (Wavelength: 0.52-0.60)

This band matches the wavelength of green seen when looking at vegetation, making it good for assessing plant vigor.



Band 3: Red (Wavelength: 0.63-0.69)

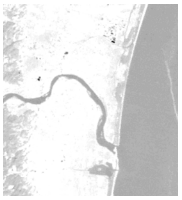
Vegetation absorbs red light, so this band is sometimes referred to as the “chlorophyll absorption band”, useful for distinguishing between vegetation and soil and monitoring vegetation health.

Band 4: Near Infrared (Wavelength: 0.77-0.90)

Since water absorbs most light at this wavelength, and vegetation reflects it, this band makes water look very dark and vegetation look very bright. These qualities make this band useful for emphasizing land-water boundaries.

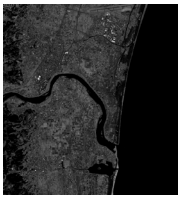
Band 5: Short-wave Infrared (Wavelength: 1.55-1.75)

This band is sensitive to the moisture content of soil and vegetation and penetrates thin clouds, making it useful in monitoring moisture content in vegetation and soil, as well as distinguishing between cloud cover and snow.



Band 6: Thermal Infrared (Wavelength: 10.40-12.50)

This band is useful for thermal mapping and estimating soil moisture, and primarily used for geological applications. This band is also used to measure heat stress and differentiate between clouds and bright soils, since clouds are typically much colder. The resolution of this band is 60 meters, half of the other bands.



Band 7: Short-wave Infrared (Wavelength: 2.09-2.35)

This band is useful for mapping hydrothermally altered rocks associated with mineral deposits. It is also used for mapping vegetation moisture, band 5 is typically preferred.

FIG. 2.2.4 Landsat 7 ETM+ Band Combinations

BANDS 3,2,1 RGB

This band combination offers a composite which appears as close to true colour, or "natural" colour, as can be achieved using Landsat data. However, since the two shortest wavelength bands, 1 and 2, are included, the image produced is typically a bit hazy.

BANDS 4,3,2 RGB

These bands offer a composite similar to the 3,2,1 combination, however, since band 4 (near infrared) is included, land-water boundaries and different types of vegetation are more easily distinguished. This band combination is commonly referred to as the standard "false colour" composite. Vegetation appears in shades of red, urban areas are cyan or light blue, and soils are various shades of brown. This band combination is commonly used for vegetation studies, and agricultural monitoring.

BANDS 4,5,3 RGB

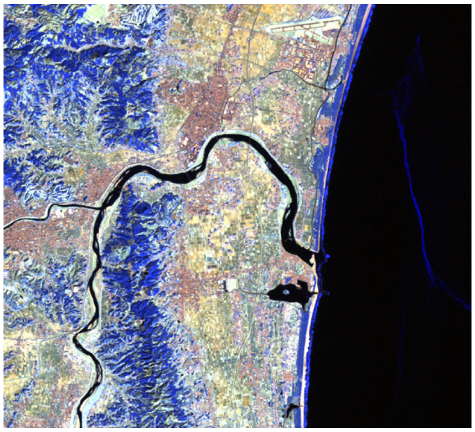
This band combination is among the most commonly used Landsat composites. Since neither band 1 or 2 are used, this band combination produces a composite which is crisper than the 3,2,1 and 4,3,2 combinations. Variation among vegetation types as well as land water boundaries are very clear. Variations in moisture content are also distinguishable. Vegetation appears in shades of brown, green and orange. Because water absorbs infrared light (band 4 and 5 are both infrared), the wetter the conditions, the darker they appear in this composite.

BANDS 7,4,2 RGB

This band combination produces a composite similar to the 4,5,3 combination, only, vegetation appears green. Healthy vegetation appears bright green, while sparsely vegetated areas appear as shades of orange and brown, and soil appears in shades of pink. This combination can be useful in identifying vegetation within urban areas. Grassy areas typically appear light green, and olive green to bright green typically indicates forested areas. Coniferous forest typically appears darker than deciduous.

BANDS 5,4,1 RGB

This band combination is similar to the 7,4,2 combination, however, it produces a composite which more clearly distinguishes agricultural vegetation.



BANDS 7,5,4 RGB

This band combination uses no visible wavelengths.

Population data was acquired acquired from NASA's Socioeconomic Data and Applications Centre (SEDAC),[9] in raster (GeoTiff) format. Finally, data describing the road network before the disaster event was acquired from OpenStreetMap,[10] in ESRI Shapefile format.

IMAGE PRE-PROCESSING

The Landsat 7 ETM+ imagery collected in the previous step needs to be pre-processed before being used for the spatial analysis described below. Firstly, the Scan Line Corrector (SLC) on the Landsat 7 satellite failed in 2003[11], and now leaves scan lines across the images it produces. While there are several methods for filling these data voids, the method used herein employs the *QGIS* raster analysis tool, *Fill nodata*. It is noteworthy that this step is done primarily to benefit visualization, and the effect this step may have on the quality of the data remains under debate.

Before Landsat data can be used for analysis, a conversion process of the underlying spectral data is required. More specifically, the spectral data collected by the satellite is converted from reflectance values to a *digital number* (DN) as a part of the remote sensing process. Landsat satellites map reflectance values taken by their sensor to the range 0 to 255, to ease data transmission from the sensor by reducing its complexity, while maintaining the ability for each band to be easily viewed as a grayscale image.

With this in mind, among the first steps in using Landsat data for spatial analysis is to convert DN's to reflectance data, and many methods, of varying complexity, exist for doing so. The work presented here uses *QGIS* and *GRASS* to covert DN's to Top of Atmosphere Reflectance with simple Dark Object Subtraction (DOS1) atmospheric correction.[12]

FIG. 2.2.5 24 February 2011 Landsat 7 ETM+

Pre-disaster image of the Fukushima Coast, before scan-line correction and image processing.

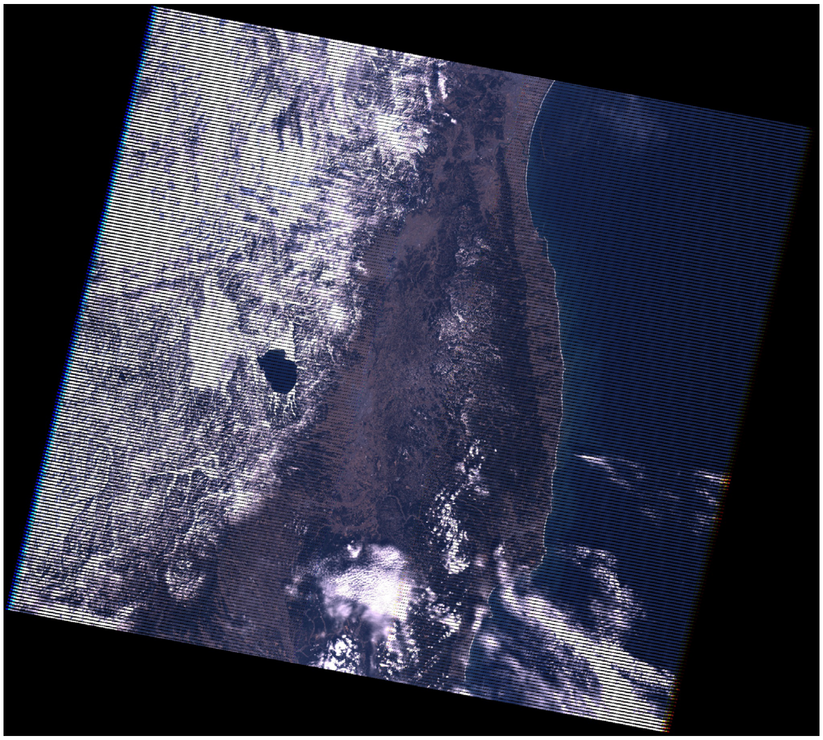


FIG. 2.2.6 12 March 2011 Landsat 7 ETM+

Post-disaster image of the Fukushima Coast, before scan-line correction and image processing.

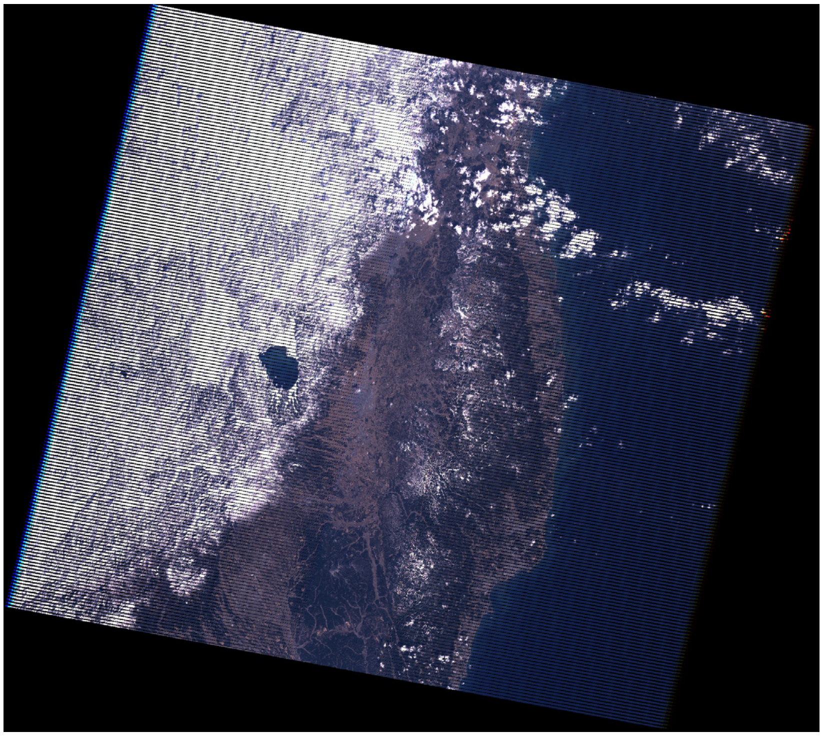


FIG. 2.2.7 24 February 2011 Landsat 7 ETM+, Bands 3, 2, 1

Pre-disaster "natural" colour composite image.

24 FEBRUARY 2011 / LANDSAT 7 ETM+ BANDS 3,2,1

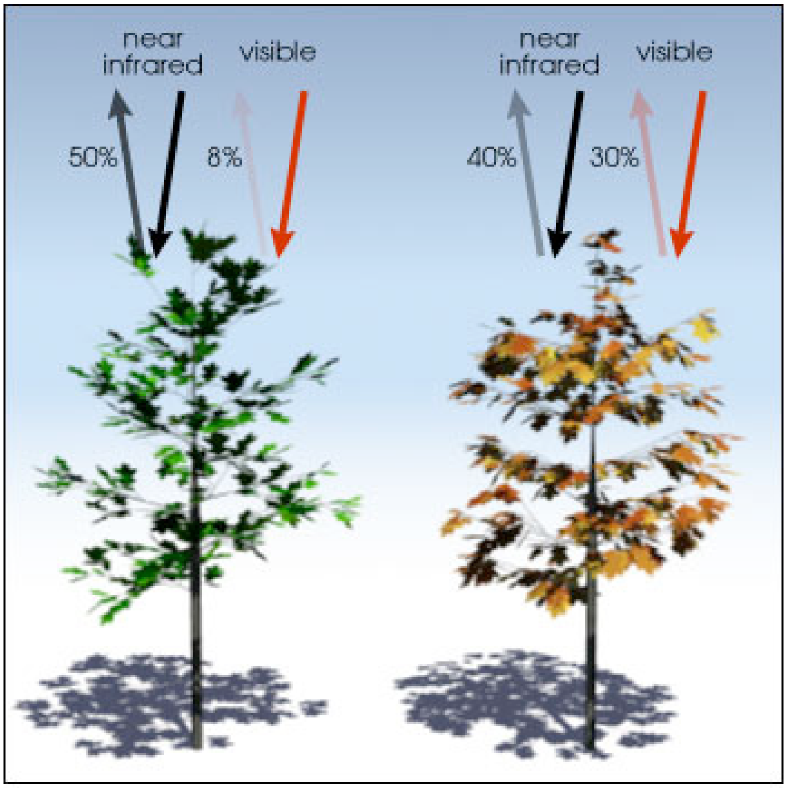
FIG. 2.2.8 12 March 2011 Landsat 7 ETM+, Bands 3, 2, 1

Post-disaster "natural" colour composite image.

As a further step in pre-processing Landsat data, *QGIS* is employed to mask clouds out of the imagery, assigning "nodata" values to covered areas.[13] This step helps ensure that cloud covered areas are not mistaken for other spatial features.

NDVI INUNDATION MAPPING

A Normalized Difference Vegetation Index (NDVI) is a graphic indicator commonly used to determine the health and density of vegetation across a patch of land.[14] In its typical usage, NDVI leverages the difference between the way plants absorb and reflect visible and near-infrared light. Since the chlorophyll in plant's leaves strongly absorbs visible light, and the cell structure of the leaves strongly reflects near-infrared light, the density of leaves in an area strongly affects



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

FIG. 2.2.9 Wavelength Reflectance

Healthy and dense plants absorb most visible light, and reflect most near-infrared light. Conversely, unhealthy or sparse vegetation reflects more visible light and less near-infrared light.

the reflectance of these wavelengths.[15] More specifically, healthy and dense plants tend to absorb most of the visible light that hits them, while reflecting most near-infrared light. Similarly, unhealthy or sparse vegetation tends to reflect more visible light and less near-infrared light than its healthier and denser counterpart.[16]

While outside of this common usage, it has been demonstrated that NDVI can also be used to assess flooding and inundation.[17] Since water greatly absorbs near infrared light, inundation greatly effects NDVI.[18] NDVI values range from -1 to 1, and within this range, water covered areas are typically represented by negative values. With this in mind, it has been shown that inundated areas can be determined as those that were positive before a flooding event, and have become negative after the event.[19] In the case considered in this work, Landsat 7 ETM+ image data collected on February 24, 2011 is used as a *before* image, and data collected on March 12, 2011 – the day after the earthquake and Tsunami – is used as an *after* image.

NDVI is calculated using near-infrared (NIR) and visible (VIS) spectral wavelength data as follows:[20]

NDVI = (NIR-VIS)/(NIR+VIS)

Since Landsat 7 band 3 and band 4 represent red (visible) and near-infrared light respectively, they can be used to calculate NDVI as follows:

NDVI = (Band 4 – Band 3)/(Band 4 + Band 3)

As such, an NDVI image is produced by applying this calculation to each pixel across a region of interest; a process computed within this work using the *QGIS Raster Calculator*[21]

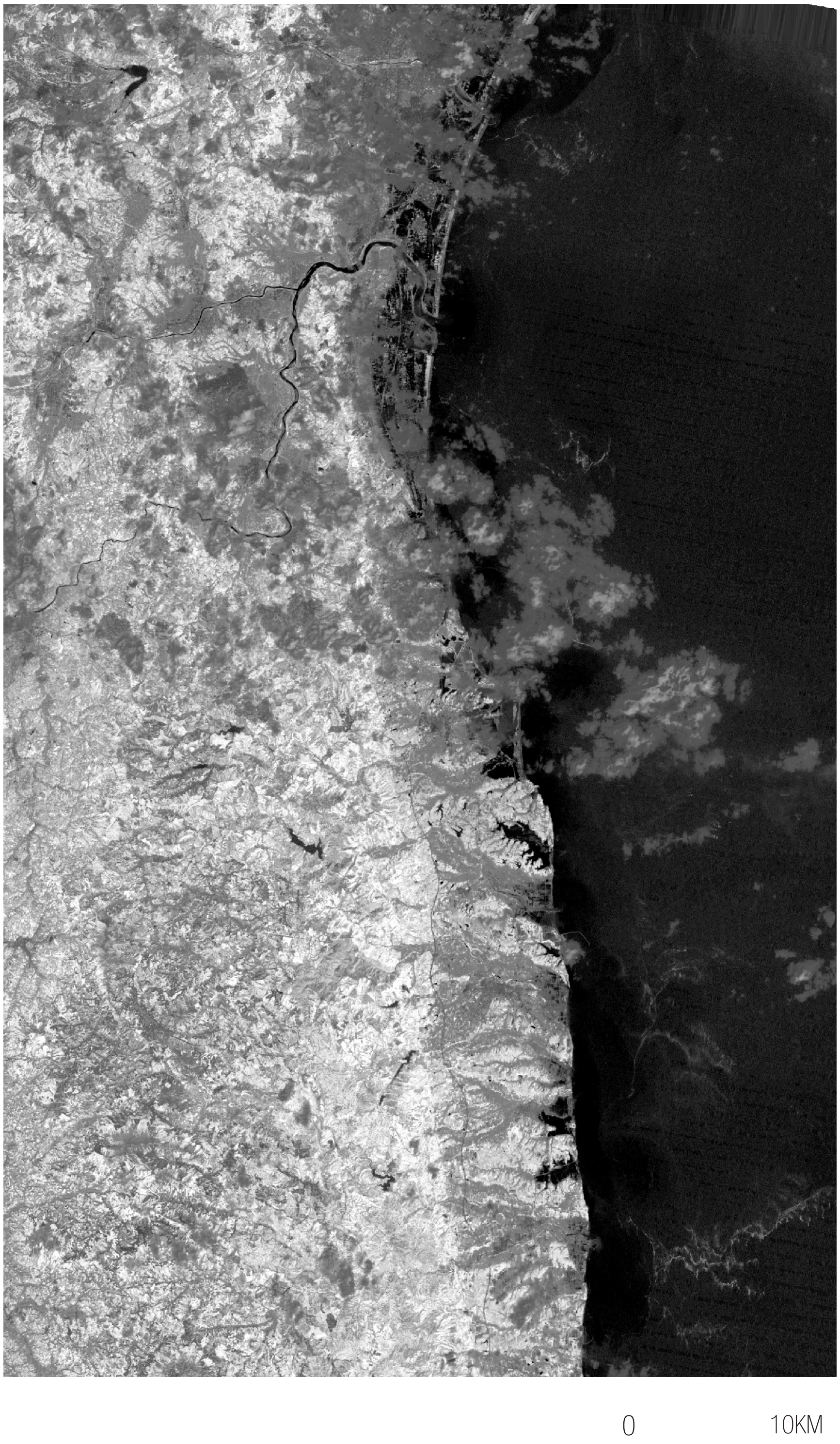
Using this method, NDVI's were calculated using both the *before* and *after* data collected, and then compared to identify areas previously characterized by positive NDVI values, which had become negative after the earthquake and tsunami event.

FIG. 2.2.10 24 February 2011 NDVI

Pre-disaster Normalized Difference Vegetation Index.

FIG. 2.2.11 12 March 2011 NDVI

Post-disaster Normalized Difference Vegetation Index.



12 MARCH 2011 / NDVI

FIG. 2.2.12 24 February 2011 NDVI

Pre-disaster Normalized Difference Vegetation Index colour visualization.

FIG. 2.2.13 12 March 2011 NDVI

Post-disaster Normalized Difference Vegetation Index colour visualization.

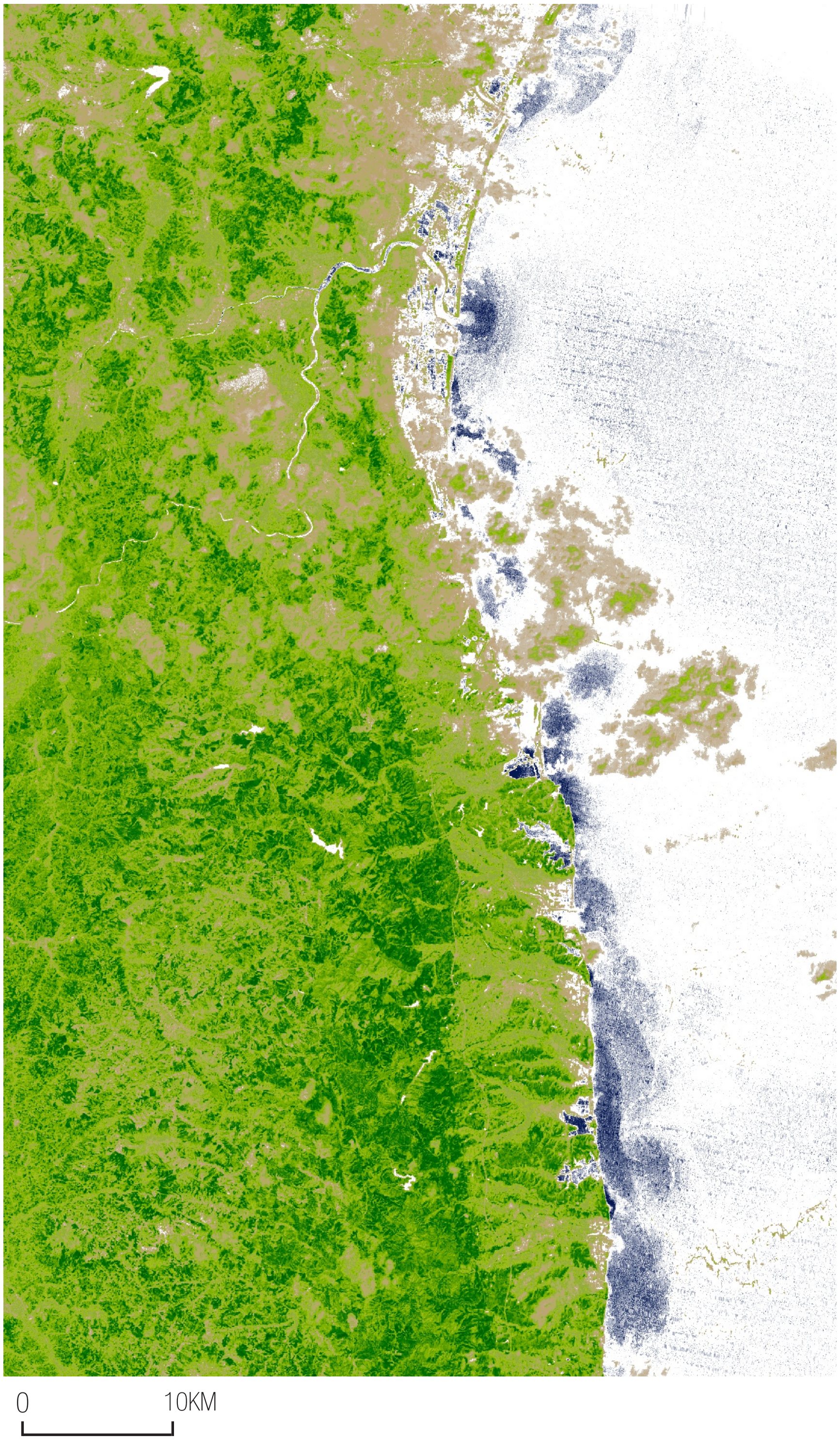


FIG. 2.2.14 Digital Elevation Model

A digital elevation model, used to calibrate NDVI based inundation mapping.

FIG. 2.2.15 Digital Elevation Model, Hillshade Visualization

A Hillshade visualization of the DEM used to calibrate NDVI based innundation mapping.

DIGITAL ELEVATION MODEL / HILLSHADE

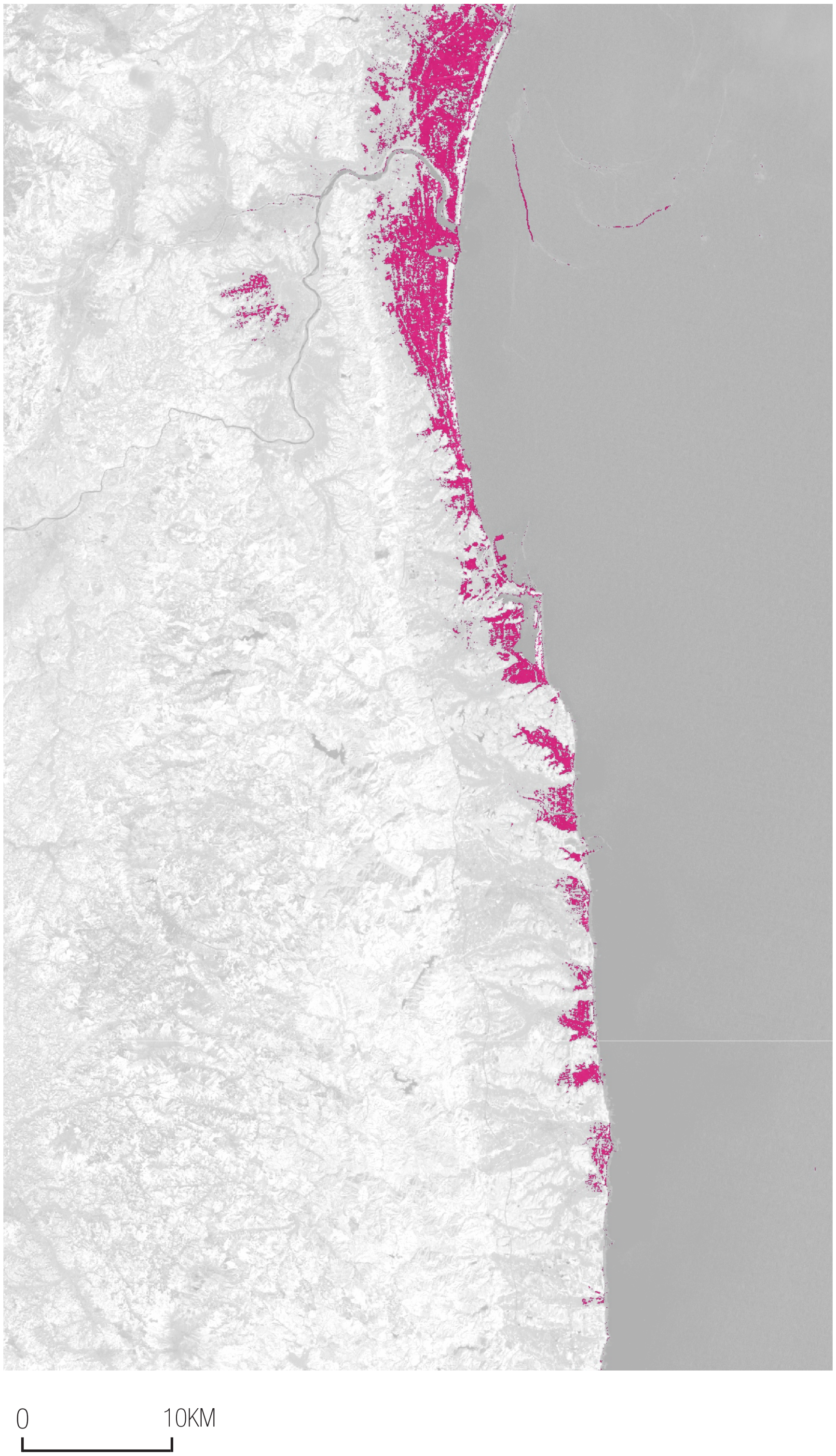


FIG. 2.2.16 NDVI Inundation Map

A comparison of NDVI values before and after the disaster, reveals inundated areas by identifying regions which had positive values before the event and negative values afer the event.

The map is further calibrated using a digital elevation model to isolate areas susceptible to inundation, such as those below 10 m in elevation above sea level.

It has also been demonstrated that a digital elevation model can be used to calibrate this type of study by isolating areas which might be susceptible to inundation, such as those below 10m in elevation above sea level, and disregarding areas which fall outside this zone.[22] In this work, the QGIS Raster Calculator was again used to process this comparison.

CHANGE DETECTION

Change detection techniques are used to identify areas which have changed between two or more observations of a particular location.[23] Such changes can be due to a variety of causes, and can occur abruptly, or over long periods of time.[24] As such, change detection is commonly used for applications such as land use monitoring, natural resource management, and damage mapping, and a variety of algorithms exist for dealing with this range of applications, depending on the data used to characterize the scene and the temporal scale of the event being observed.[25]

For applications like land use monitoring and natural resource monitoring, multi-temporal sets of images are typically used to detect changes which have occurred over longer periods of time, where identifying when changes have occurred can be as critical a concern as detecting altered spatial characteristics.[26]

For applications like damage mapping, as demonstrated in the work that follows, abrupt changes, where the date of change is typically known, are usually the principal concern. As such, pairs of images, before and after the event, are most commonly used for such applications.[27]

Using the same pair of images used in the previous section (NDVI Inundation mapping, see above), the work that follow employs the *Orfeo Toolbox, Multivariate Alteration Detector*[28] to identify changes resulting from the earthquake and tsunami, as a means of mapping the

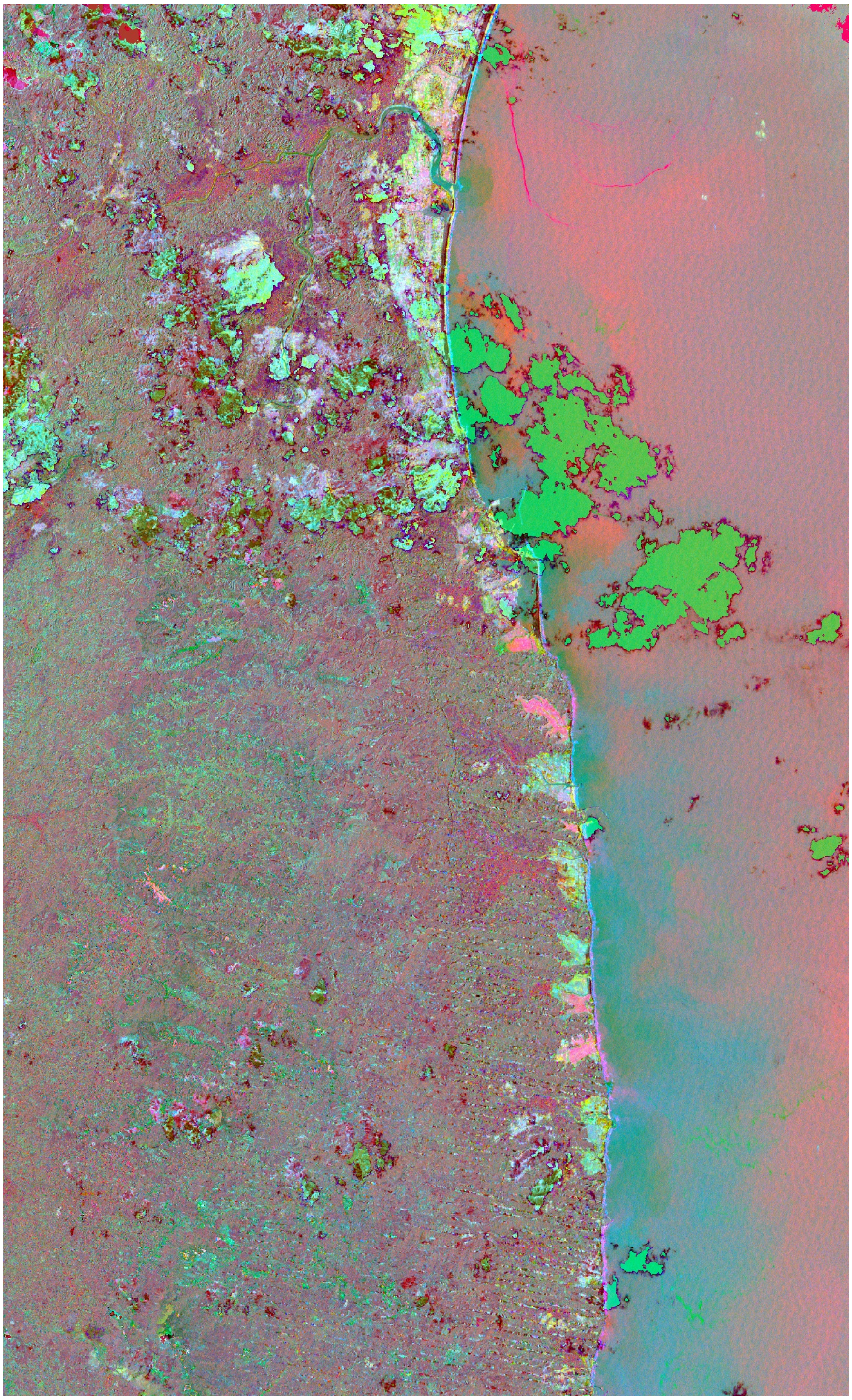


FIG. 2.2.17 Multivariate Alteration Detection

general scope of damage which occurred. While the previous section identifies areas inundated following the tsunami, this section aims to identify the greater extent of damage due to the event, including areas which do not suffer from inundation.

LAND COVER CLASSIFICATION

Land cover is the "(bio)physical cover" observed on the surface of the earth, and land cover classification is a process of abstracting and representing such field conditions using a well-defined system of criteria and arrangements. [29] Many standardized systems of classification exist, for a range of data types and resolutions, however, classification can also utilize custom categories for specific mapping endeavours. For instance, flood maps may include only two categories – dry land and wet land – whereas a standard land cover map may include several, and far more specific categories, such as shrub lands, savannahs, evergreen needle leaf forests, ice and snow, urban areas, and so on.[30]

Regardless of the number of categories, a land classification system typically includes certain qualities, which allow the definition of clear class boundaries. For instance, a good classification system will be "scale independent," meaning that the classes offered by the system can be applied at any level of detail for the area under consideration. [31] Similarly, a classification system should also be "source independent", meaning, independent of the means used to collect the data from which classification is based. [32]

The land cover classification technique used in the work that follows employs the *Semi-Automatic Classification Plugin (SCP),* available from within the *QGIS Plugin Manager.*[33] The SCP uses a "supervised" approach to classification, meaning it relies on specification of training data by the user, and is used in the work that follows to classify the area of interest into the following classes: *urban, cropland, other vegetation, and water.*

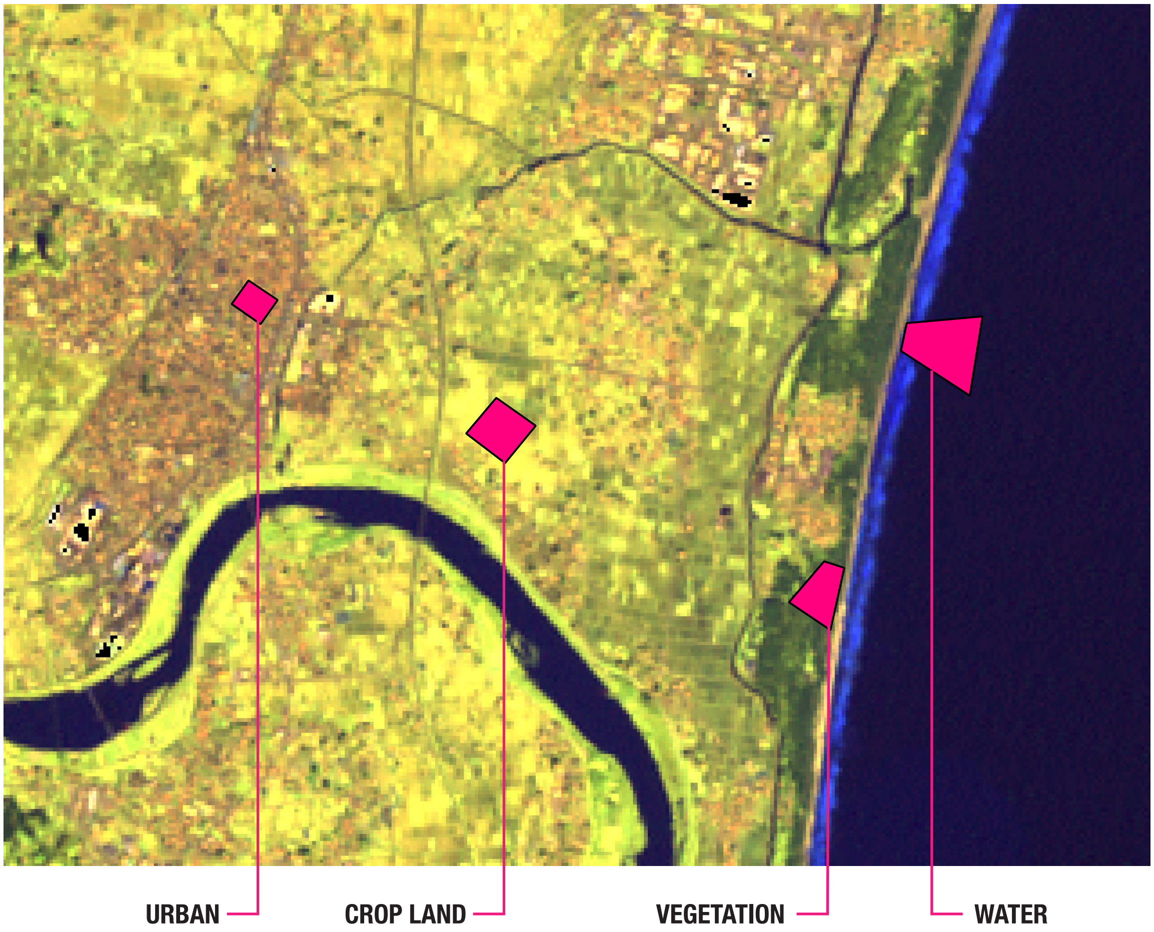
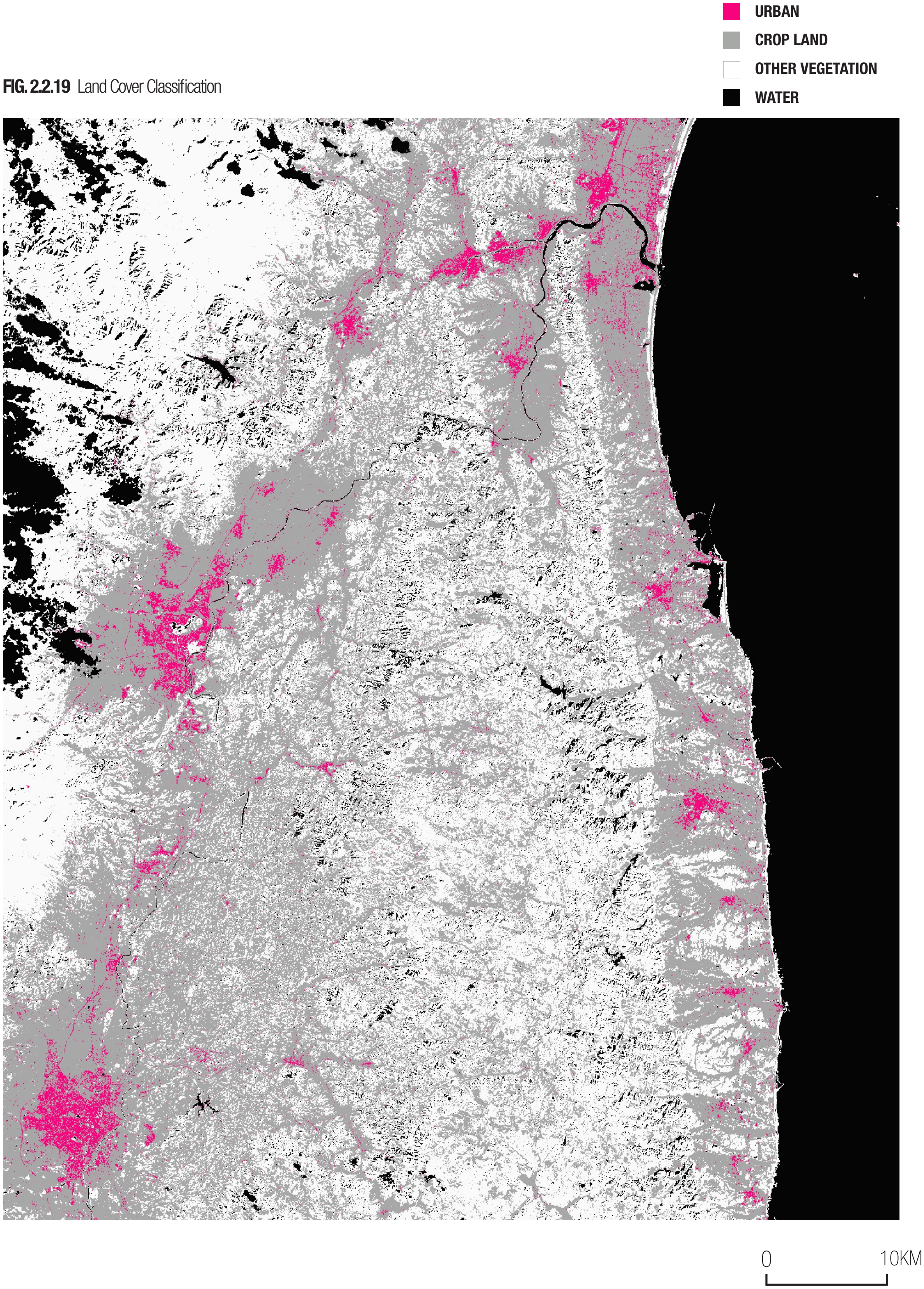


FIG. 2.2.18 Land Cover Classification, Training Data Sample Regions

FIG. 2.2.19 Land Cover Classification



LAND COVER CLASSIFICATION

SPATIAL CLUSTERING & EMERGENT REGIONALIZATION

In contrast to the classification technique used in the previous section, this stage employs an unsupervised form of classification which integrates the data collected and maps created in the previous sections, into a damage map to be used in the *modelling* phase, and a map of priority areas to be used in the *formation* phase.

In broad terms, cluster analysis is a process of abstraction which organizes data into useful or meaningful groups or *clusters*.[34] Of course, what is "useful" or "meaningful" is relative to the research at hand, and an array of clustering strategies have been developed to address a range of research priorities and constraints. However, as a general condition, the greater the similarity within a cluster and the greater the heterogeneity between clusters, the more effective the clustering implementation.[35]

This project assumes an unsupervised, non-hierarchical approach, implementing a partitioning around medoids (PAM) clustering algorithm[36] as its principal method for cluster analysis. As an unsupervised approach, no training data is used to inform the process of clustering. Where supervised learning, or classification, relies on a priori knowledge of a given set of labeled classes that exist within a data set, and develops a model accordingly (as in the land cover classification above), unsupervised learning works to reveal a natural grouping

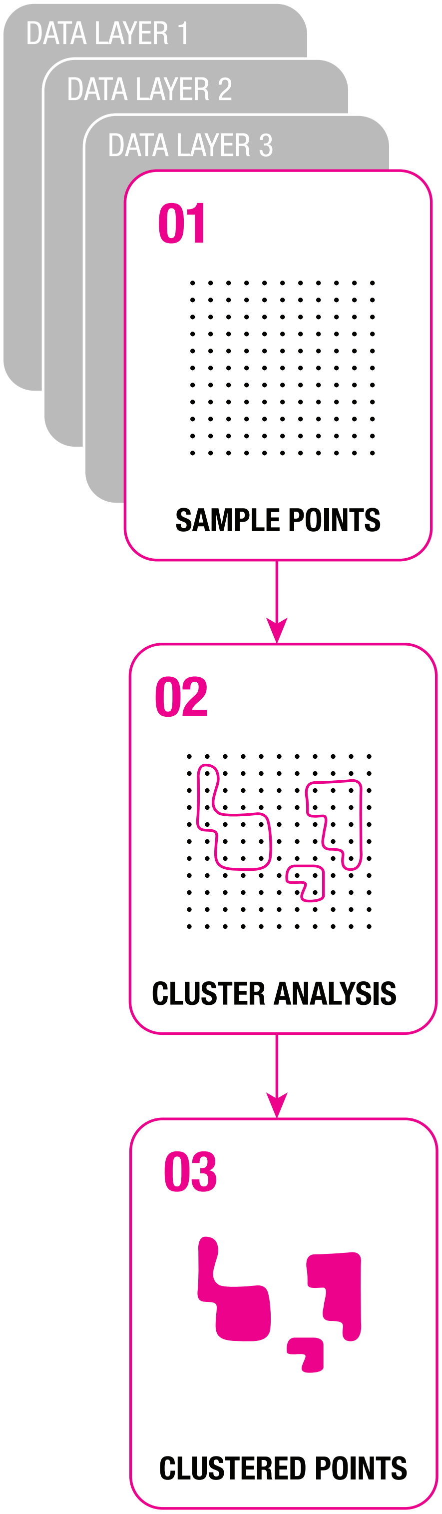


FIG. 2.2.20 Spatial Cluster Analysis Process Diagram

Data layers are assembled in QGIS, and a gird of points is overlayed. Data from each layer is sampled and attributed to each point in the grid, and a table containing this new collection of data is exported as a spreadsheet.

The R programming language is used to import the spreadsheet containg the new data collection, and perform a Partition Around Medoid (PAM) cluster analysis.

A revised spreadsheet containg the data collection from the previous step, as well as an additional attribute indicating a cluster group is then exported.

The spreadsheet from the previous step is then imported back into QGIS and processed for visualization.

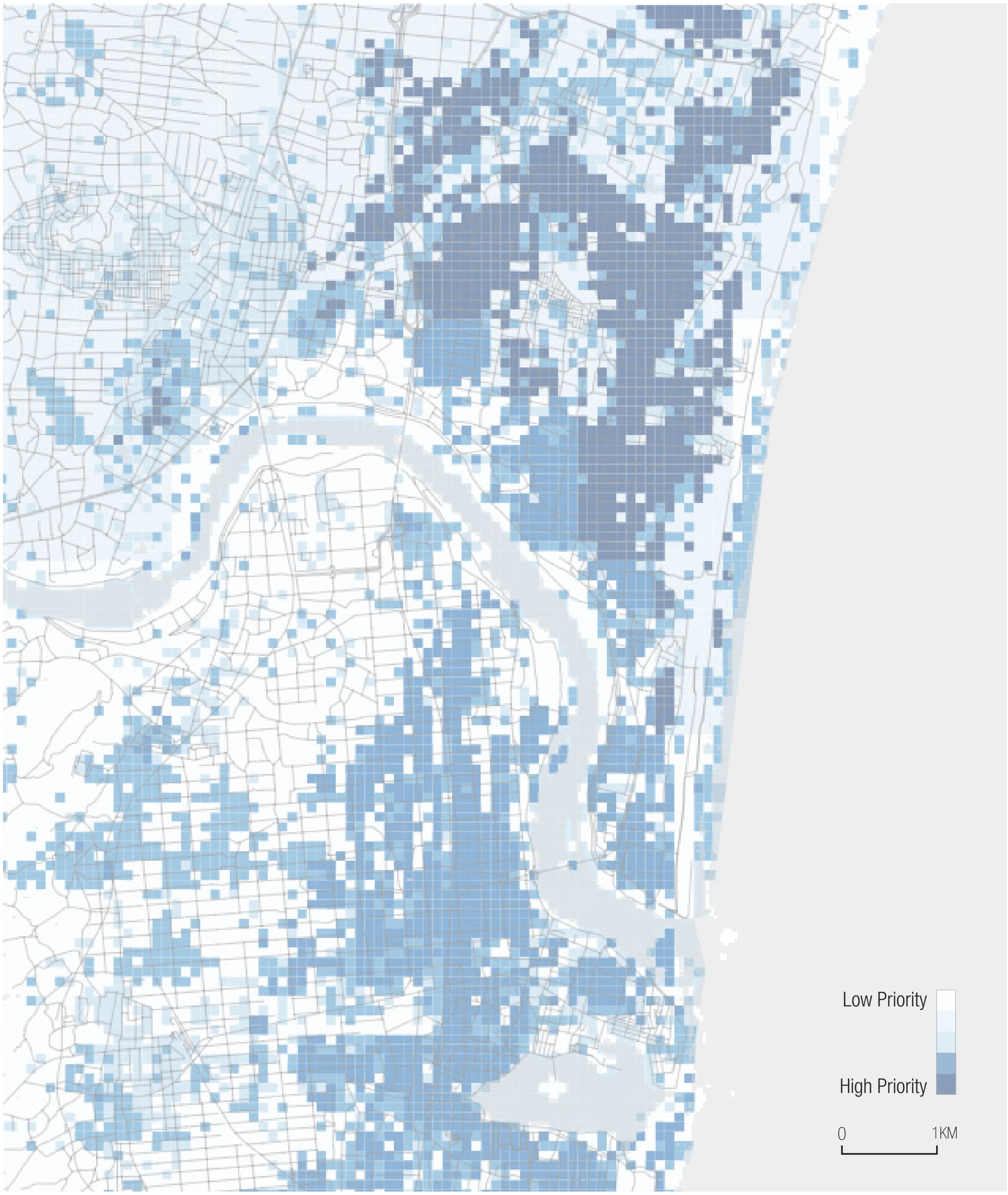


FIG. 2.2.21 Spatial Cluster Analysis, Prioirty Regions

Priority regions are characterized by land cover, population density, and degree of damage. High priority regions include those within built-up land cover, with high population densities, and high degrees of damage. Conversely, low priority regions include those outside of built-up land cover, with low population densities, and low degrees of damage.

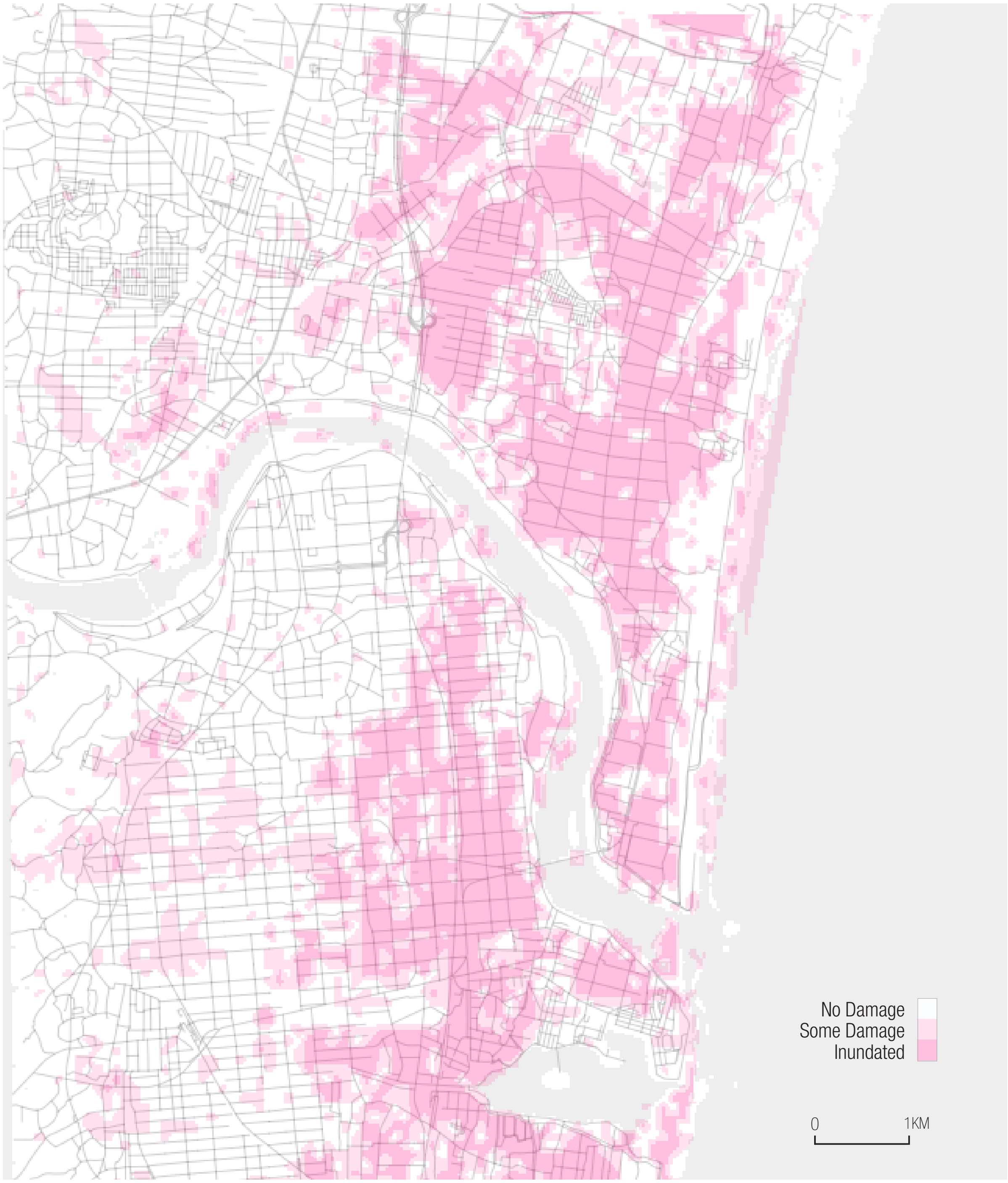


FIG. 2.2.22 Spatial Cluster Analysis, Damage Map

structure within an unlabeled data set, and presents it as a set clusters or a *clustering*. As a non-hierarchical approach, the data is organized into non-overlapping subsets of data objects, placing each object in exactly one cluster. [37]

EXPORT FOR ABM

The final step in this implementation of the *discovery* phase is to convert the damage map, road map, and population data into formats that allow their use as inputs for the *modelling* phase that will follow. As such, QGIS is employed to export each of these *discovery* outputs in ASCII format.

ENDNOTES

1 Science Education through Earth Observation (SEOS) Project, n.d.

2 Horning, 2004

3 Science Education through Earth Observation (SEOS) Project, n.d.

4 USGS Earth Resources Observation and Science Center (EROS), 2014

5 Ministry of Economy, Trade, and Industry (METI) of Japan, United States National Aeronautics and Space Administration (NASA), 2014

6 Ibid.

7 Ibid.

8 Ibid.

9 Socioeconomic Data and Applications Center (SEDAC); A Data

Center in NASA's Earth Observing System Data and Information System (EOSDIS), hosted by CIESIN at Columbia University, 2014

10 OpenStreetMap, 2014

11 USGS, 2014

12 i.landsat.toar , 2014

13 i.landsat.acca, 2014

14 Weier & Herring, 2000

15 Ibid.

16 Ibid.

17 Li, Liu, Guan, & Peng, 2011, p. 3

18 Ibid.

19 Ibid.

20 Weier & Herring, 2000

21 Raster Calculator, 2014

22 Li, Liu, Guan, & Peng, 2011, p. 3

23 OTB Development Team, 2014

24 Ibid.

25 Ibid.

26 Ibid.

27 Ibid.

28 Ibid.

29 Department, Natural Resources Management and Environment, n.d.

30 Graham, 1999

31 Department, Natural Resources Management and Environment, n.d.

32 Ibid.

33 Installing and managing plugins, 2014

34 Cluster analysis: Basic concepts and algorithms, 2006, p. 488

35 Ibid, p. 490

36 Hollander, 2011, p. 26

37 Cluster analysis: Basic concepts and algorithms, 2006, p. 492

MODELLING & SIMULATION

SYSTEMS SIMULATION: AGENT BASED MODELLING FOR HUMANITARIAN AID

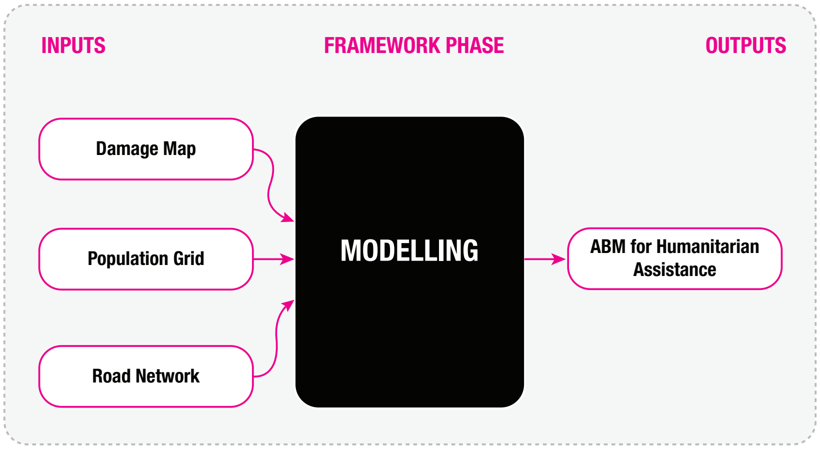


FIG. 2.3.1 Modelling Black-Box Diagram

At the center of the framework rests an agent-based model (ABM), developed to utilize a variety of open geospatial data to aid in humanitarian assistance. Using geographic data which describes population density, relative level of devastation, transportation networks and the location of aid resources (See Ch. 2.2), the ABM simulates how a population may react to an aid distribution scenario.

The ABM produces maps which anticipate the movement of people and information about aid availability through the environment, as well as a record of agent activity and the utilization of aid resources over time. Upon completion, the simulation reports statistics which describe change in population health, as a product of the given aid scenario.

By offering a view of the emergent phenomena which result from the interactions the model simulates, the ABM can be used to explore the effects design iterations may have on their context. Accordingly, the ABM structures the environment for design exploration used in the exploration phase that follows (see Ch. 2.5).

The ABM was originally developed by Crooks and Wise as a response to the earthquake which struck Haiti in 2010,[1] but, more broadly, as an open source tool to aid in humanitarian assistance and research. The model is constructed using MASON, a java-based lightweight multi-agent simulation toolkit, developed by George Mason University's Evolutionary Computation Laboratory and Center for Social Complexity. MASON's structure lends itself well to use within a larger research and design framework, as it is separates its core model from visualization and user interface, facilitating ease of integration into wider projects. Similarly, MASON is not a domain-specific toolkit, which makes it suitable for tasks which aim to integrate multivariate disciplinary perspectives, as suggested herein.

The version of the ABM implemented in this work adapts the model by Crooks and Wise for use in the context of the 2011 Japan earthquake and tsunami. While data used within the model has been modified,[2] its primary structure and key processes remain the same.

DATA INPUTS

As inputs, the model uses the road network, population data, and damage map produced during the discovery phase (see Ch. 2.2 for details).

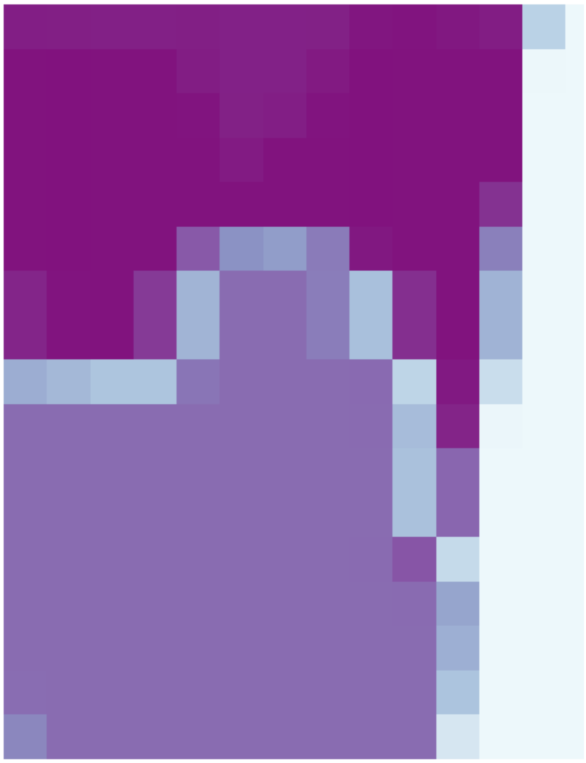
MODEL STRUCTURE

The ABM is principally comprised of two types of actors, namely, Aid Distribution Centres and Agents, each of which are established based on the above mentioned model inputs. Similarly, Aid Centres and Agents both exist and act within an environment, represented by a grid, which is also defined and characterized by model inputs.[3] In this case, the grid represents an area of approximately 10km^{2,} with a resolution of 100m2 per grid point.

The model moves forward in set increments, or "time steps", where each step represents 5 minutes of "real world time."[4] Such time steps are easily adjusted, depending on the temporal scale under consideration. Similarly, with each step, each of the actors operate within the environment according to a set of key processes, further described in the work that follows.

FIG. 2.3.2 Road Network

FIG. 2.3.3 Population Data



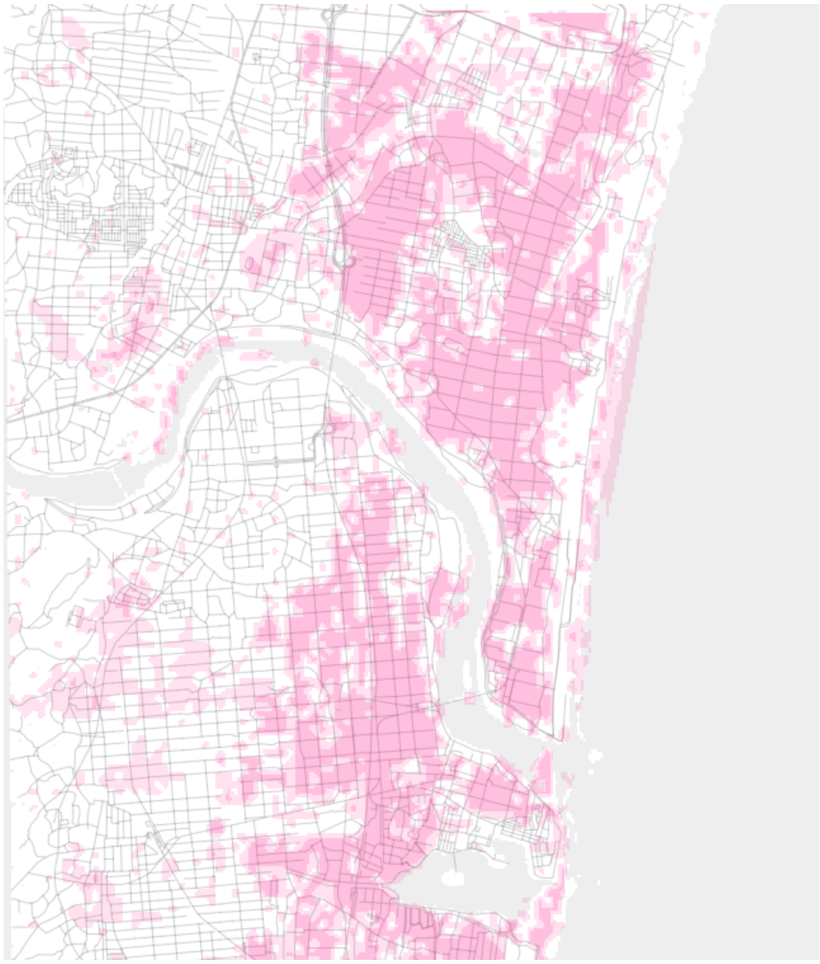


FIG. 2.3.4 Damage Map

MODEL PARAMETERS

TYPE	PARAMETER	VALUE
Agents	Initial energy level, based on location	No Damage: 2000 Some Damage: 1200 Inundated: 1000
Environment	Maximum number of Agents per 100m^2	10
Centres	Amount of food initially available at each centre	20
	Amount of energy an agent receives from one unit of food.	500

FIG. 2.3.5 Table of ABM Parameters

AID DISTRIBUTION CENTRES

Aid Centres distribute resources and supplies, as the models mechanism for providing the basic needs of survival to the local population. In model terms, Crooks and Wise describe Aid Centres as both "locations" and "actors."[5] Centres are "locations" because they can't move and only one can exist at any given grid point.[6] Centres are "actors" because they play an active role in the simulation, distributing aid to Agents which enter their location.[7]

At model initialization, Aid Centres are given a set amount of supplies, and can only distribute what they have in stock.[8] While supplies can be re-stocked throughout the simulation, they aren't re-supplied in the default instance of the model used in this work.[9] Once an Aid Center runs out of supplies, it turns away agents empty handed.[10]

AGENTS

Agents are the ABM's representation of the population. As a disaggregate model,[11] the population is not represented collectively, rather, each Agent is a representation of an individual member of the population. Motivated according to Maslow's Hierarchy of Needs, each agent's primary goal is to acquire basic resources for survival, offered at each Aid Distribution Center.[12] In pursuing this goal, each agent can move independently, make decisions, and communicate with other Agents.[13] Agents also maintain an energy level, affected by their movement and the conditions they encounter, as well as knowledge of their environment, including the location of their home and an awareness of Aid Center locations.[14]

An Agent's energy level is its most important attribute, as an abstracted reflection of its health.[15] Agents use energy with each time step in the simulation, according to what they are doing, and the conditions of the environment at the time.[16] Crooks and Wise describe this as "…emulating a metabolism…"[17] An Agent's initial energy level is determined based on the conditions of the environment surrounding

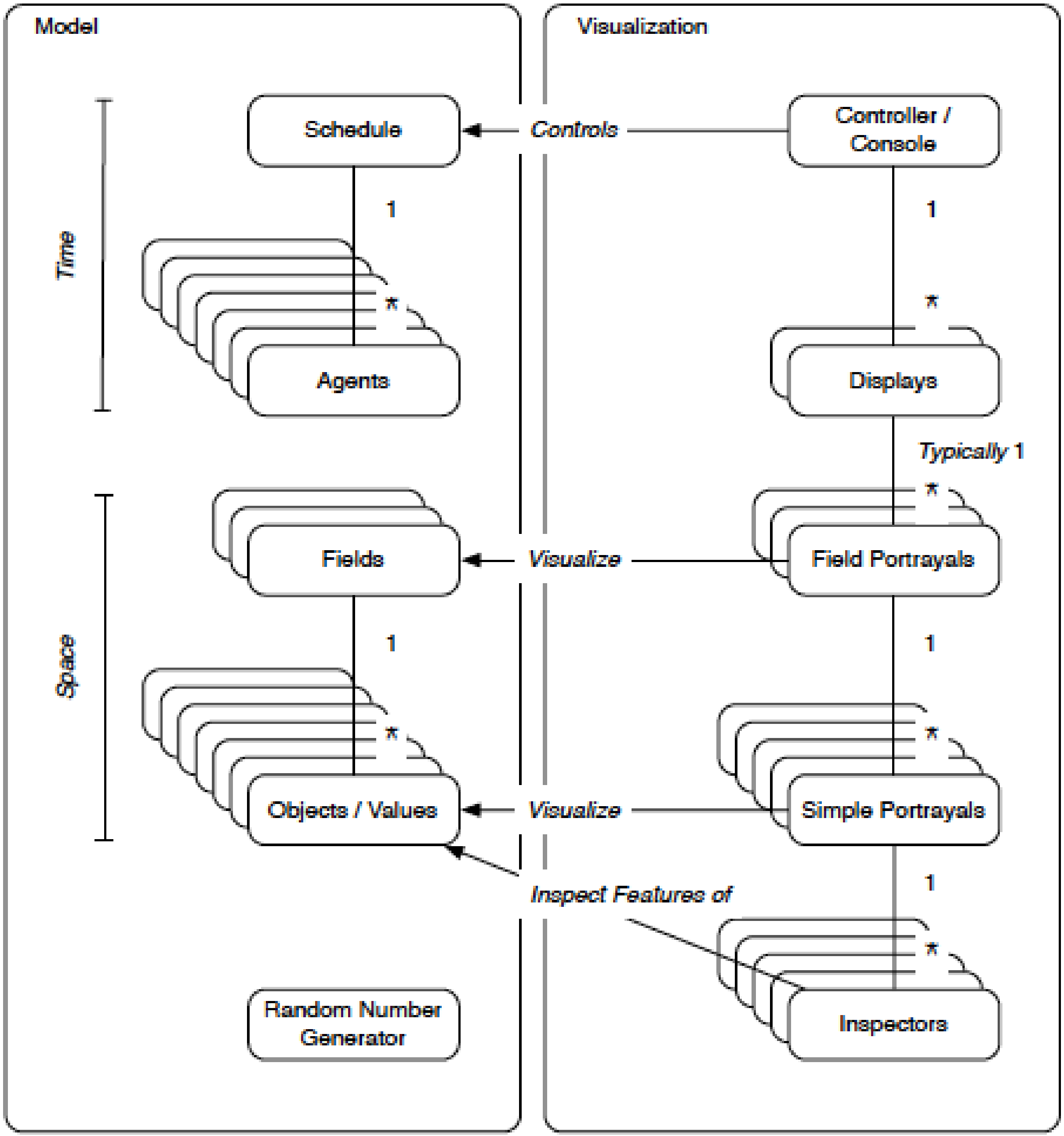


FIG. 2.3.6 MASON Structure

MASON separates model from visualization and interface, making it easy to integrate its core functionality into wider projects.

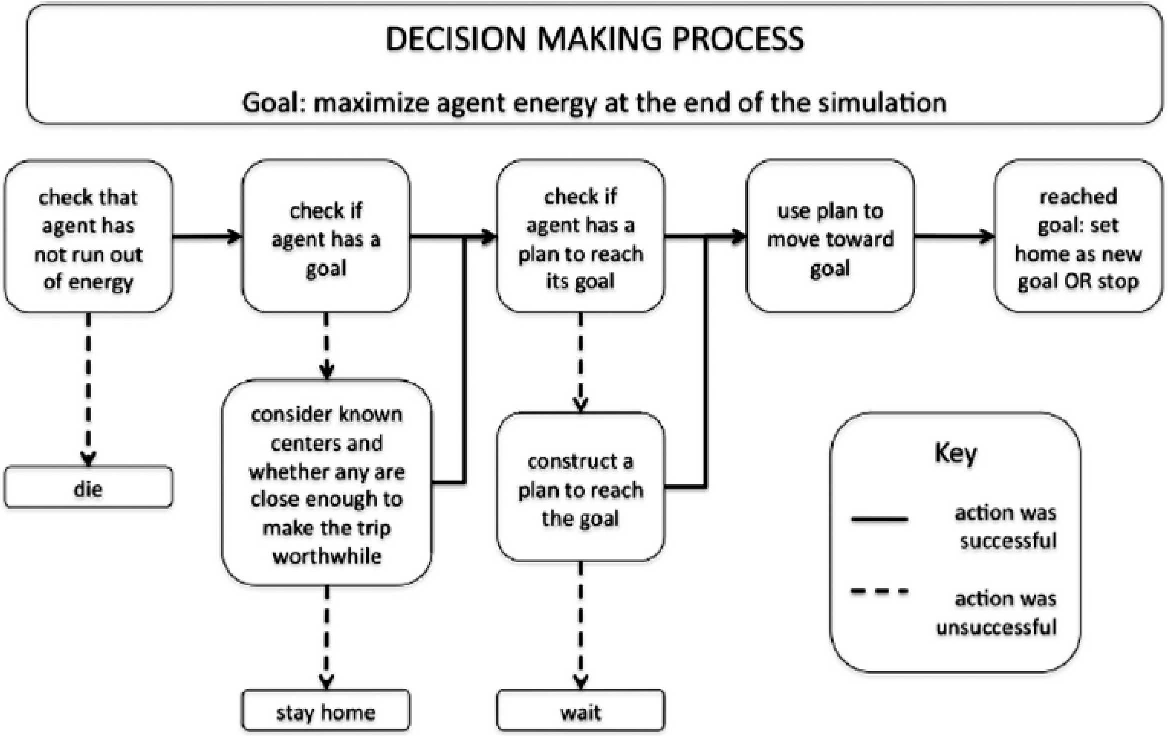


FIG. 2.3.7 Agent Decision Making Process

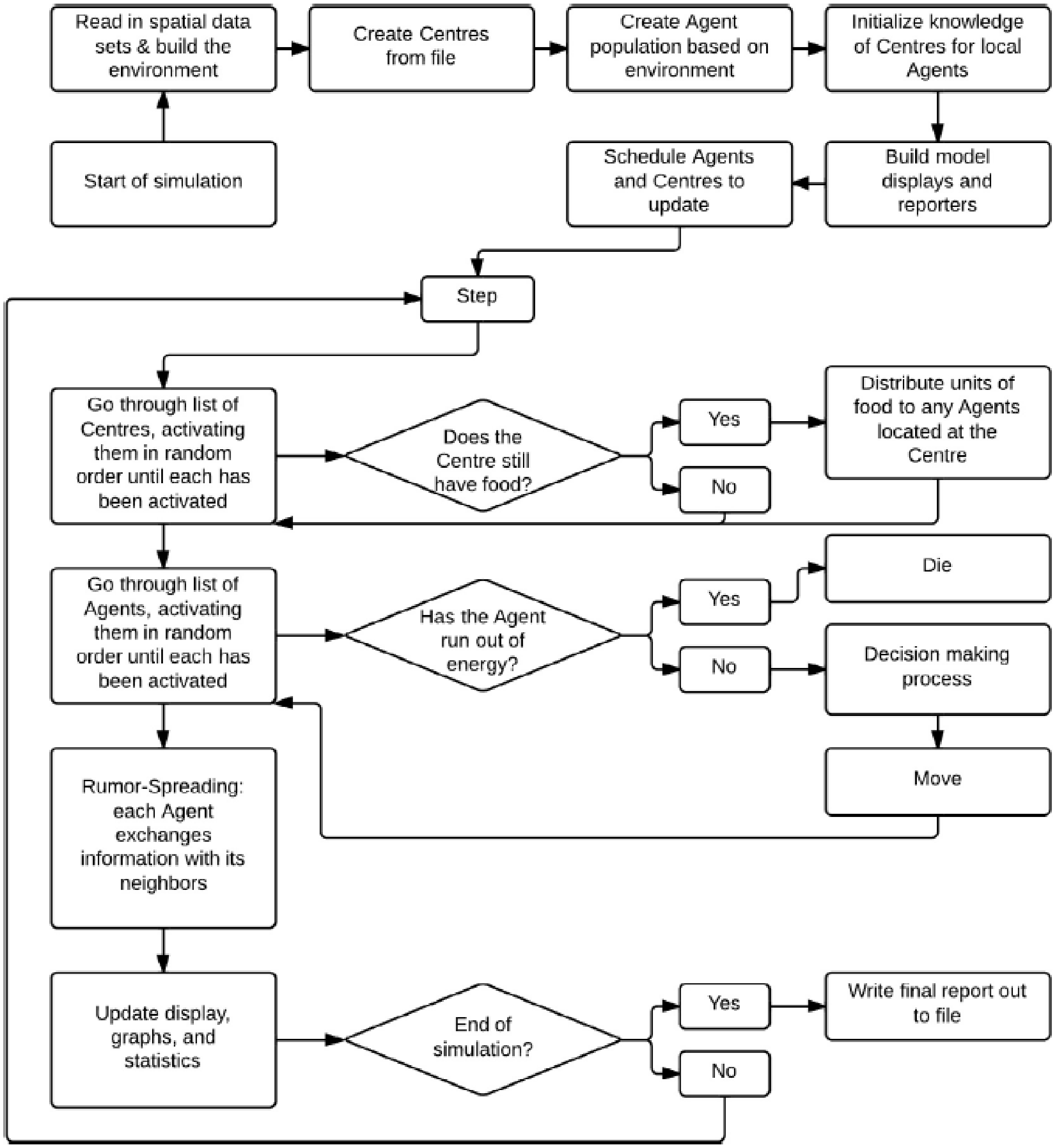


FIG. 2.3.8 Flow Diagram of Key Process in the Model

their home.[18] Upon receiving aid, an Agent's energy level increases, and when an Agent's energy level is fully depleted, it dies.[19]

AGENT DECISION MAKING

In an effort to maximize their energy level, each Agent can choose to either stay at home or walk to an Aid Distribution Center, basing the decision on their knowledge of the road network and aid availability.[20] Each Agent considers the cost of movement to and from an Aid Center versus the expected energy benefit from receiving aid, and chooses whether or not to pursue aid based on the anticipated net benefit.[21] Agents also continually reassess their plan. For instance, if they learn about an Aid Center, on route elsewhere, they will reconsider and update their plan accordingly.[22]

Agents use an A* algorithm to plan their route, using knowledge of the road network.[23] Here, it is important to note that Agents are not aware of post-disaster road damages, so any decision they make is based on their knowledge of the road network before the crisis. As a result, Agents actual path and energy cost may differ from their expectation, based on the real conditions they encounter.[24]

An important note regarding Agent movement is, Agents typically move at approximately 100m per step.[25] However, this rate is affected by the population density of their current location. If the max density of an area has been reached, Agents are prevented from moving until the density of the population surrounding them lessens.[26]

AGENT COMMUNICATION AND THE SPREAD OF INFORMATION

Agents acquire information about Aid Distribution Centers through "rumour-spreading."[27] Agents keep track of information they have acquired and share it with other agents who pass within a small area around them.[28] When the model is initialized, Agents near Aid Center locations "witness" the establishment of the Center and start to spread information about it and its supplies.[29]

Another note regarding Agent communication is, Agents never lie.[30] However, Agents also do not spread information about resource depletion, so it is possible that false information remains in circulation.[31] The consequence of this is that, Agents can continue to pursue an Aid Distribution Center, only to be turned away without supplies upon arrival.

MODEL OUTPUTS

At the end of a simulation run, the model outputs statistics about the number of Agent deaths, the cumulative energy level for the entire population of Agents, and the number of unused units of aid. Results are presented in normalized terms, meaning the number of deaths are described as a ratio to population size, and energy levels are described as a ratio to the number of surviving Agents.[32]

The cumulative energy level for the population is intended to offer a measure of overall population health.[33] The intention is that, considering population health in tandem with the number of deaths offers a more holistic assessment of the overall success of an Aid Distribution Network.[34] As an example, consider a scenario where there are two Agent deaths but a high level of overall population health, compared to a scenario in which there are no Agent deaths, but, there is a low level of overall population health. The remaining output, the number of unused units of aid, is intended to further broaden the assessment of a network by offering a measure of distribution effectiveness.[35]

ENDNOTES

1 (Crooks & Wise, Haiti: Natural Disaster and Crowdsourcing, 2012)

2 Degrees of destruction has been reduced to 3, based on the resolution of input data, and initial energy levels have been modified accordingly.

3 Crooks & Wise, GIS and agent-based models for humanitarian assistance, 2013, p. 103

4 Ibid, 104

5 Ibid, 104

6 Ibid, 104

7 Ibid, 104

8 Ibid, 104

9 Ibid, 104

10 Ibid, 104

11 (Batty, 2009)

12 Crooks & Wise, GIS and agent-based models for humanitarian assistance, 2013, p. 104

13 Ibid, 104

14 Ibid, 104

15 Ibid, 104

16 Ibid, 104

17 Ibid, 104

18 Ibid, 105

19 Ibid, 104

20 Ibid, 105

21 Ibid, 105

22 Ibid, 105

23 Ibid, 106

24 Ibid, 106

25 Ibid, 106

26 Ibid, 106

27 Ibid, 106

28 Ibid, 106

29 Ibid, 106

30 Ibid, 106

31 Ibid, 106

32 Ibid, 106

33 Ibid, 106

34 Ibid, 106

35 Ibid, 106

FORMATION

DEVELOPMENT OF AID DISTRIBUTION NETWORK SCENARIOS

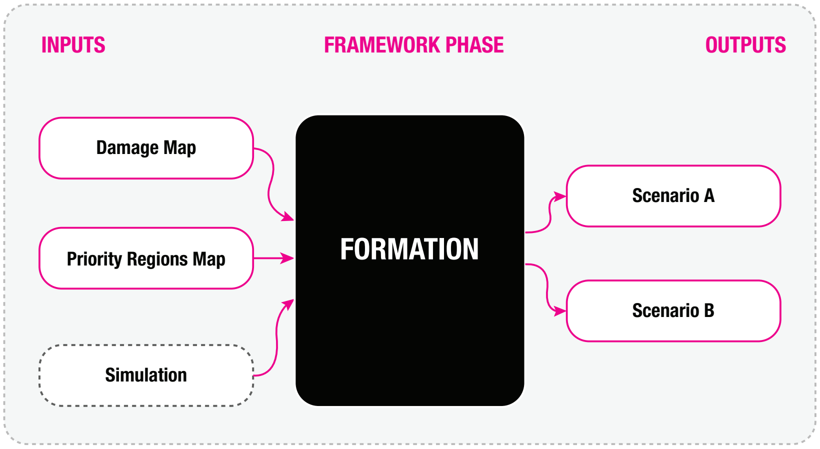


FIG. 2.4.1 Formation Black-Box Diagram

Utilizing the characterization of contextual resources and constraints developed during the *discovery* phase as inputs (See Ch. 1.3 and Ch. 2.2), the *formation* phase of the framework operates as the principle forum for design decision making, and the generation of design iterations, ensuring that the dynamics and complexity mapped and modelled during earlier phases is not left behind.

While this phase is conceptualized to operate iteratively, within a cycle of feedback with the *exploration* phase (see Ch. 2.5), the initial implementation considered herein relies solely on the products of *discovery* to establish initial aid distribution network scenarios.

In the context of this design experiment, networks of aid distribution centers are manually plotted, based on the characterization of the disaster context produced during the *discovery* phase (see Ch. 2.2), before being output to the subsequent *exploration* phase. More specifically, the priority regions map produced during *discovery* is used as a basis for plotting the potential networks of aid distribution centers.

In line with the overarching theme within this work of exploring the operation of the proposed framework, as opposed to producing a particular design outcome, this phase of the design experiment proposes two design scenarios which will be used to validate the effectiveness of the simulation employed in the subsequent *exploration* phase. As such, two simple scenarios are proposed, with the intention that the effectiveness of their implementation can be intuitively verified.

Using the Damage Map and Priority Areas Map produced during the *discovery* phase as platforms for design decision making, Scenario A proposes a network of aid distribution centres which we can intuitively understand to be well laid out, according to the information being used by the model. Centers are adjacent to high priority areas, meaning, they are close to built-up or urban areas with medium to high population density which suffered damage during the storm. Yet, the centers remain accessible by roads which are relatively undamaged.

SConversely, in Scenario B, two of the three aid centers are almost completely surrounded by severely damaged and inundated areas, making access by the population very difficult. With this in mind, it is anticipated that Scenario A will support a greater degree of population health than Scenario B in the *exploration* phase of the following chapter.

FIG. 2.4.3 Scenario A, Priority Regions Map

Aid distribution centers are located near medium to high priority regions, but outside of the most severly affected areas.

Priority regions are characterized by land cover, population density, and degree of damage.

High priority regions include those within built-up land cover, with high population densities, and high degrees of damage.

Conversely, low priority regions include those outside of built-up land cover, with low population densities, and low degrees of damage.

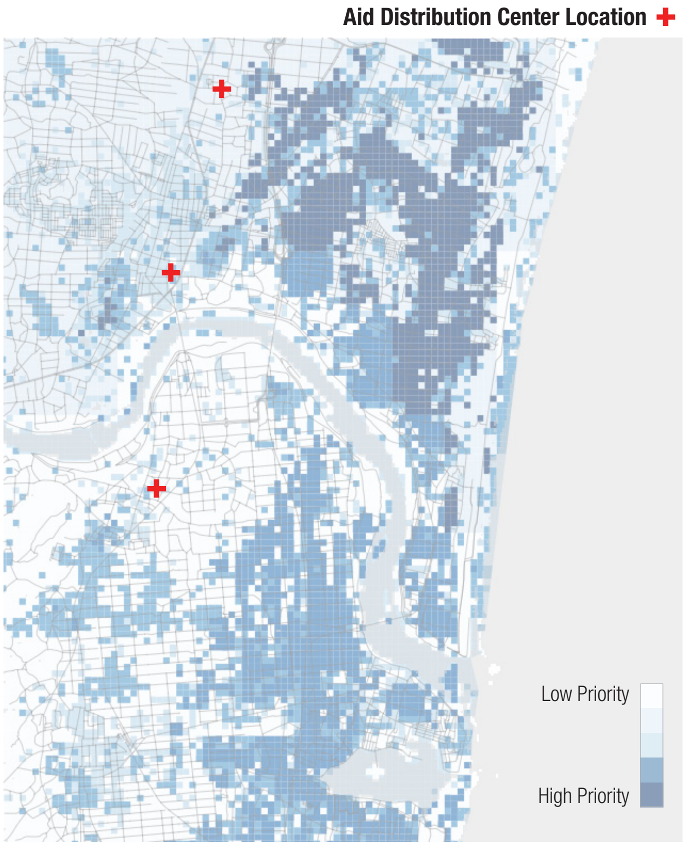
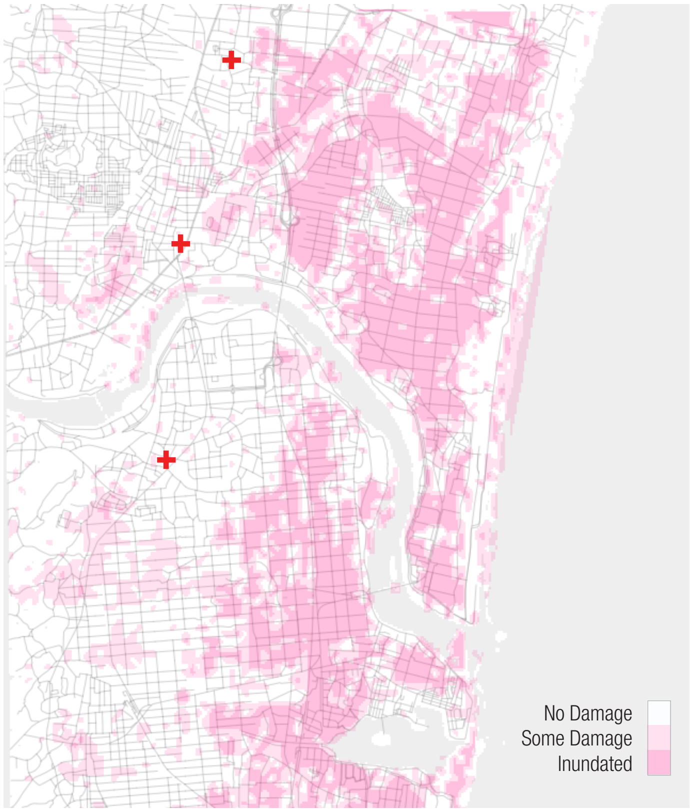


FIG. 2.4.2 Scenario A, Damage Map

Aid distribution centers are located near damaged areas, but remain accessible by undamaged roads.

This condition is intentionally set out to create a "good" scenario, for the purpose of intuitive model validation in the subsequent exploration phase.



A

Aid Distribution Center Location ✚

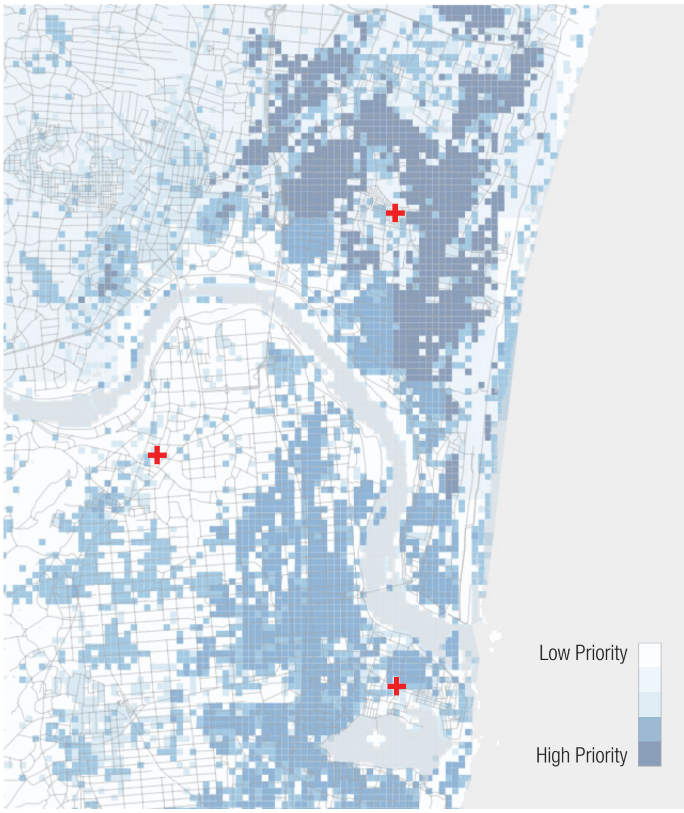


FIG. 2.4.5 Scenario B, Priority Regions Map

Aid distribution centers are located immediately within the highest prioirty zones.

Priority regions are characterized by land cover, population density, and degree of damage.

High priority regions include those within built-up land cover, with high population densities, and high degrees of damage.

Conversely, low priority regions include those outside of built-up land cover, with low population densities, and low degrees of damage.

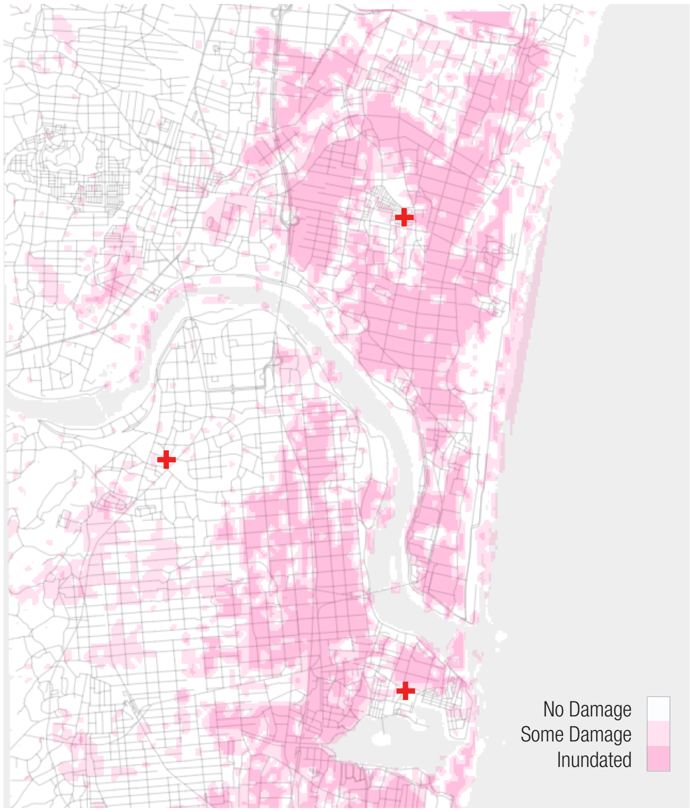


FIG. 2.4.4 Scenario B, Damage Map

Despite being located within high prioirity zones, two of three Aid distribution centers are difficult to access due to road damage and inundation.

This condition is intentionally set out to create a “poor” scenario, for the purpose of intuitive model validation in the subsequent exploration phase.

B

EXPLORATION

SIMULATING THE EFFECTS OF DESIGN INTERVENTION

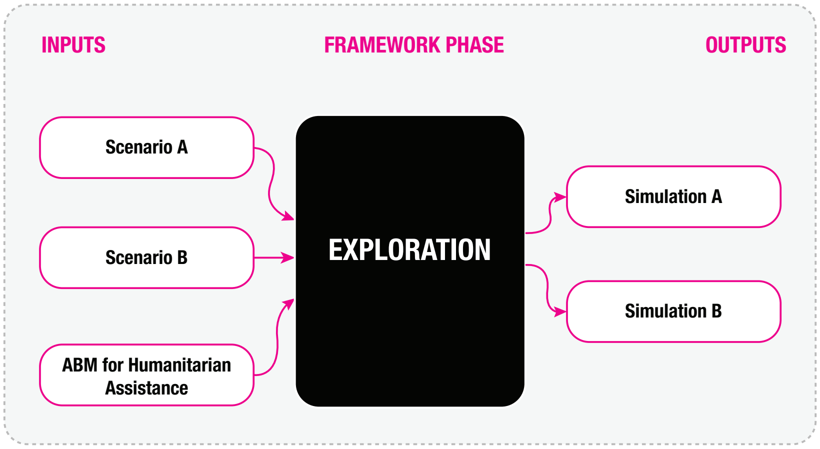


FIG. 2.5.1 Formation Black-Box Diagram

As introduced in Ch. 1.3, the *exploration* phase of the proposed framework offers a platform for design iterations to become active components within a larger systems model, and thereby offers an opportunity to explore the effects a design intervention may have on its context. As such, the *exploration* phase takes both the scenarios proposed during the *formation* phase, and the model developed during the *modelling* phase as its inputs, and offers a system simulation and contextual statistics as its outputs.

Typically, as a product of the framework, evolutionary development of a design intervention is to occur through feedback between *formation* and *exploration*, where the simulation and statistics produced during *exploration* are passed back to *formation* to inform future design iterations. However, in this initial implementation of the framework, in line with the overarching theme of exploring its operation, as opposed to developing project specific results, the *exploration* phase presented here uses each of the two scenarios created during the previous phase (see Ch. 2.4) to test the operation of the model described in Ch. 2.3.

As suggested in the previous chapter, using two scenarios, which can be intuitively assessed, offers a simple mechanism for verifying the effectiveness of the model and simulation utilized herein. As such, both scenarios developed during the previous phase are explored via the simulations presented in the figures that follow. As expected, the respective simulation of each option verifies that scenario A results in greater population health than scenario B, and affirms that the model is operating properly.

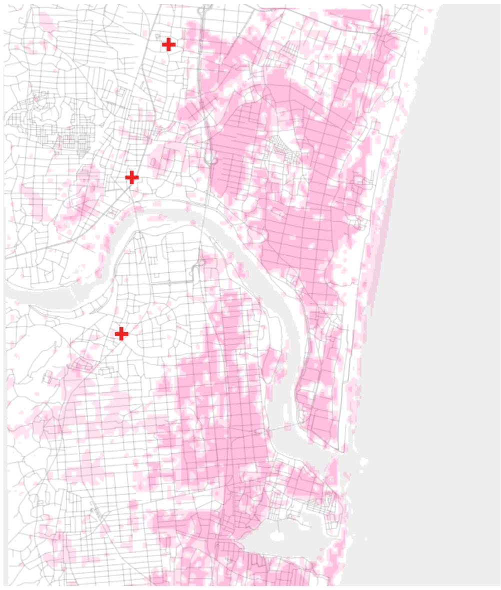


FIG. 2.5.2 Scenario A Key Maps

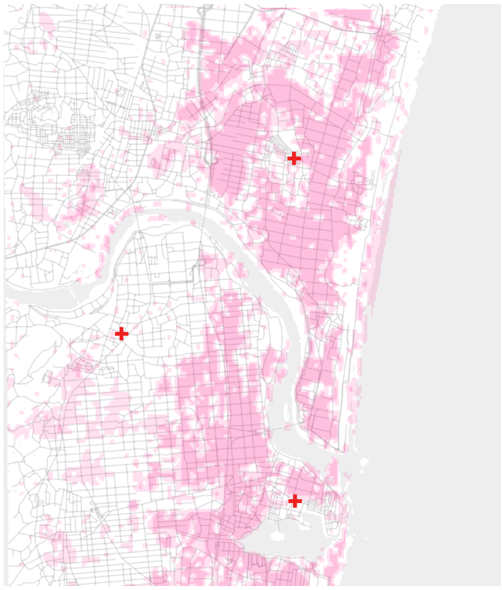
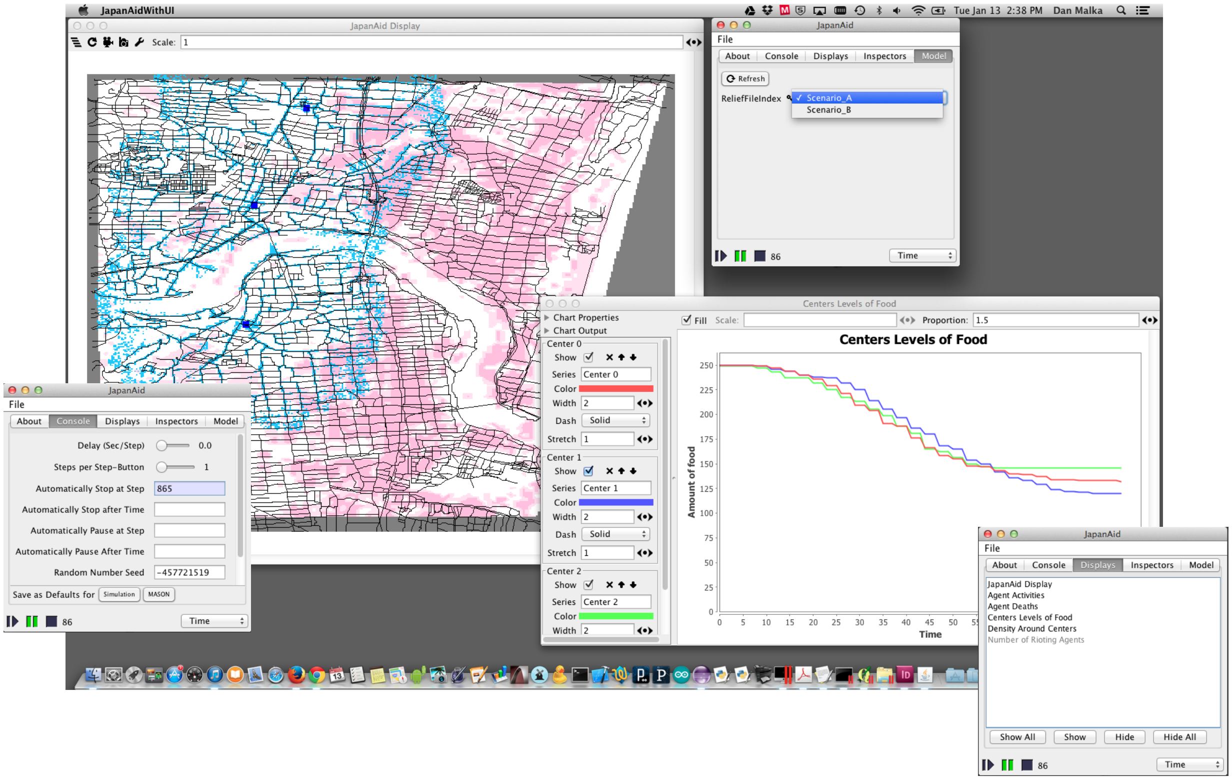


FIG. 2.5.3 Scenario B Key Maps



Scale: 1

ReliefFileIndex ✓ Scenario_A
Scenario_B

86

Delay (Sec/Step) 0.0
Steps per Step-Button 1
Automatically Stop at Step 865
Automatically Stop after Time
Automatically Pause at Step
Automatically Pause After Time
Random Number Seed -457721519

☑ Fill Scale:
Proportion: 1.5

Centers Levels of Food

Center 0
Show ☑
Series Center 0
Color 🟥
Width 2
Dash Solid
Stretch 1

Center 1
Show ☑
Series Center 1
Color 🟦
Width 2
Dash Solid
Stretch 1

Center 2
Show ☑
Series Center 2
Color 🟩
Width 2

JapanAid Display
Agent Activities
Agent Deaths
Centers Levels of Food
Density Around Centers
Number of Rioting Agents

FIG. 2.5.4 ABM User Interface

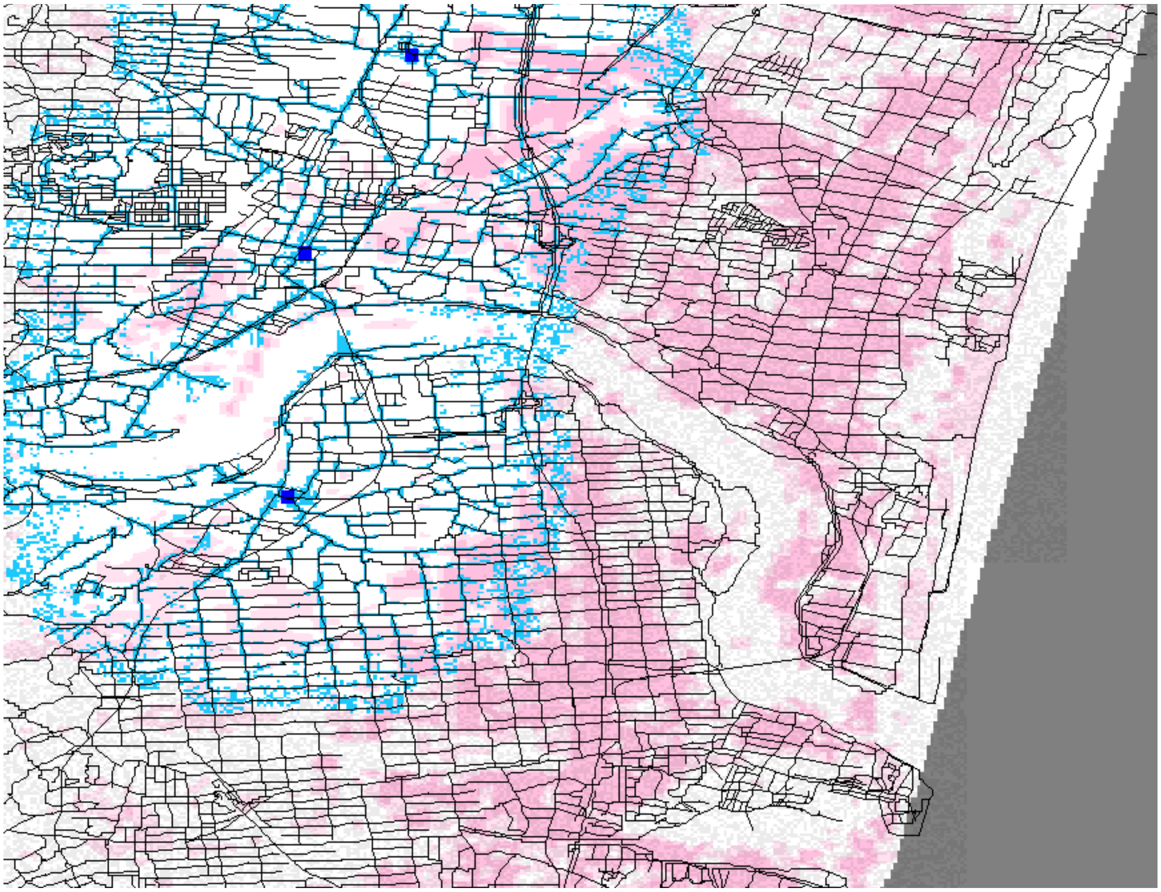


FIG. 2.5.5 Sample Simulation Screen Capture

The simulation is composed of layers, as depicted on the opposite page. Each layer can be turned on or off from the ABM user interface.

FIG. 2.5.6 Simulation: Damage

Visualization of the Damage Map, as displayed during simulation.

The Damage Map is a static input which characterizes the field of the ABM.

Blue squares represent aid distribution centre locations.

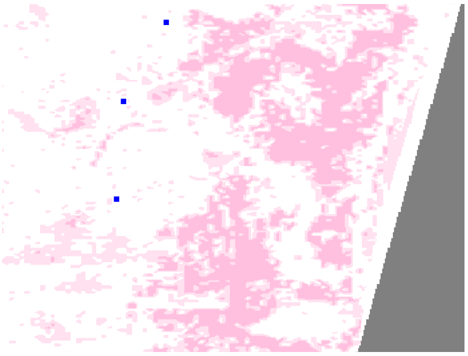


FIG. 2.5.7 Simulation: Population

Visualization of the entire populaiton of agents as displayed during simulation.

The population of agents are initially distributed according to the population density grid input in model setup.

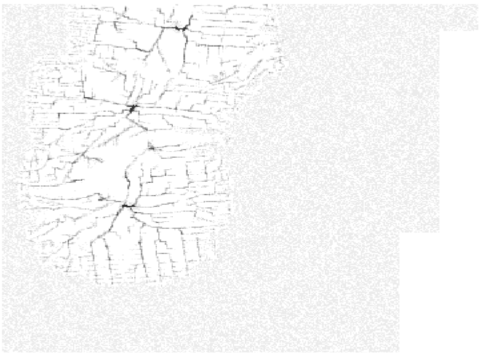


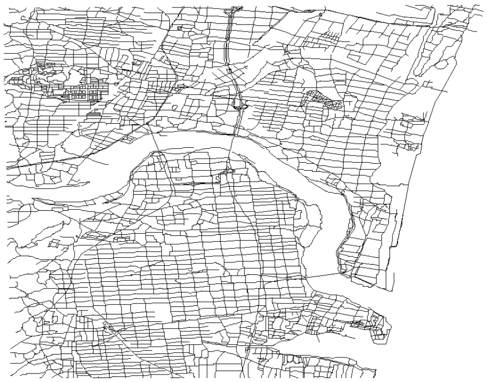
FIG. 2.5.8 Simulation: Knowledge

Knowledge about aid resources spreads outward from distribution centres as the simulation proceeds. As agents learn about centre locations, they choose whether to proceed toward them or stay home.

This layer depicts “informed” agents.

FIG. 2.5.9 Simulation: Road Network

Visualization of the road network, as displayed during simulation.



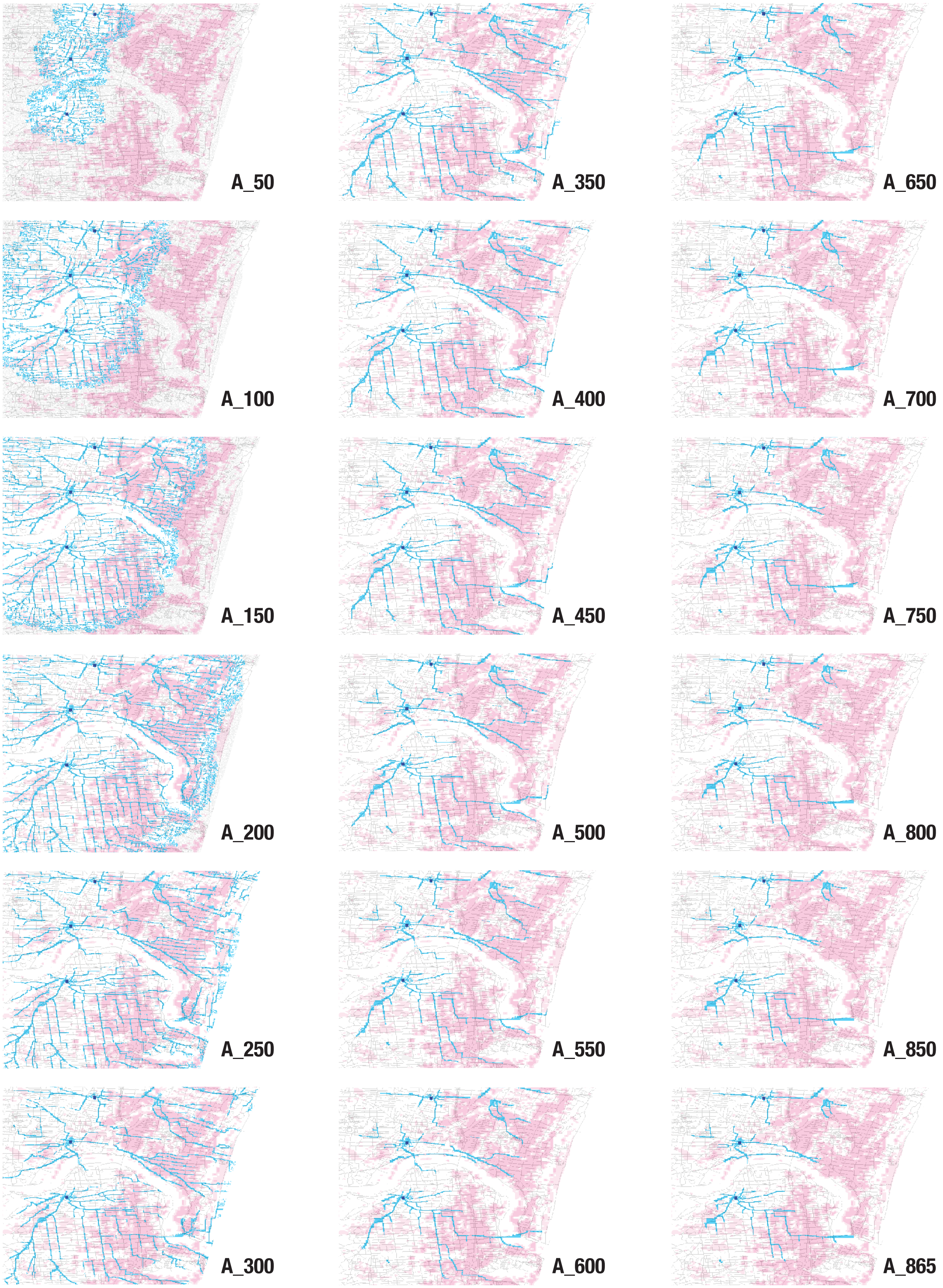


FIG. 2.5.10 Scenario A Simulation Incremental Screen Captures

A

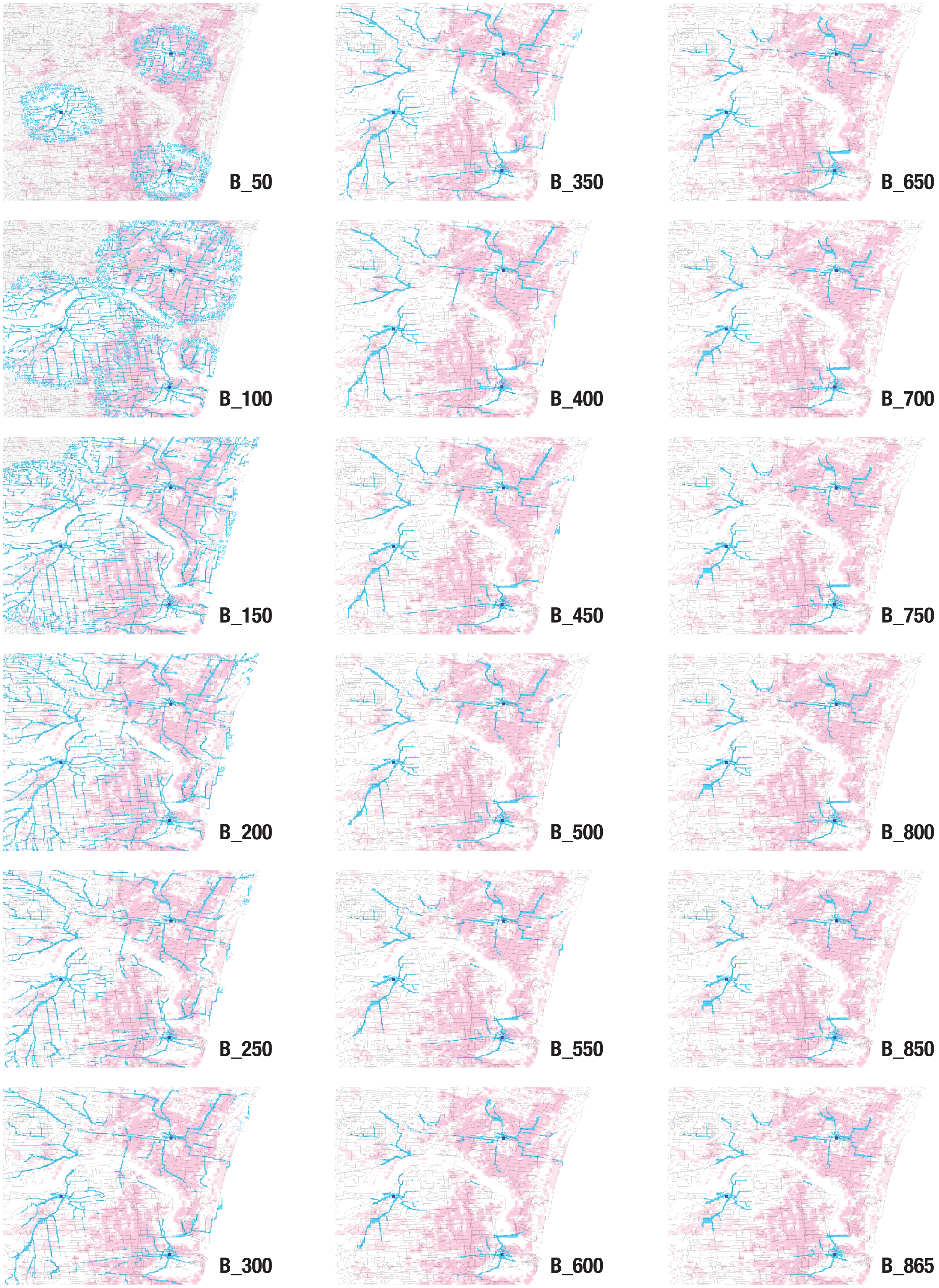
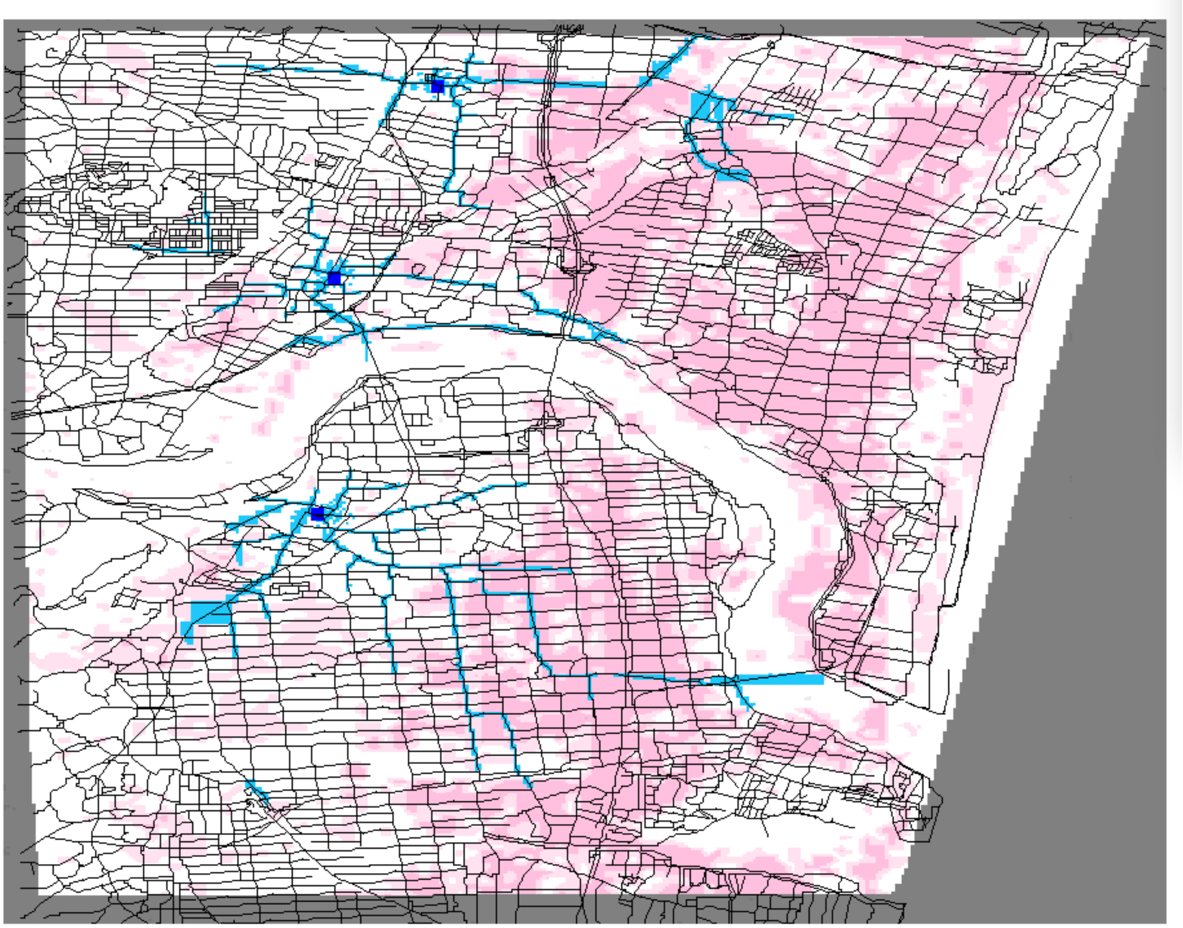


FIG. 2.5.11 Scenario B Simulation Incremental Screen Captures

B



OPTION A

FOOD LEFT AT END OF SIMULATION: 25
TOTAL ENERGY IN SIMULATION: 54058045
NUMBER OF DEATHS: 2104
STEPS IN SIMULATION: 865 (APPROX. 3 Days)

A

FIG. 2.5.12 Scenario A Simulation at Step 865

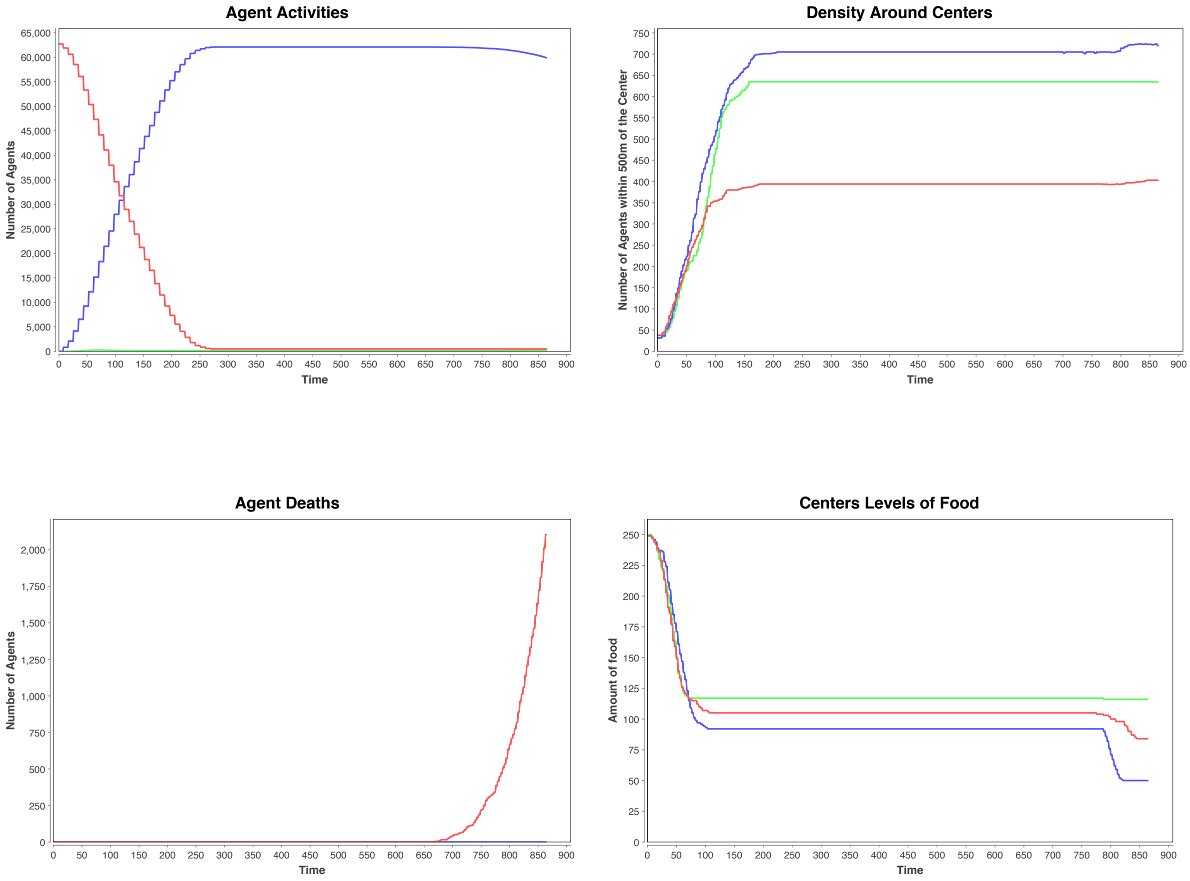
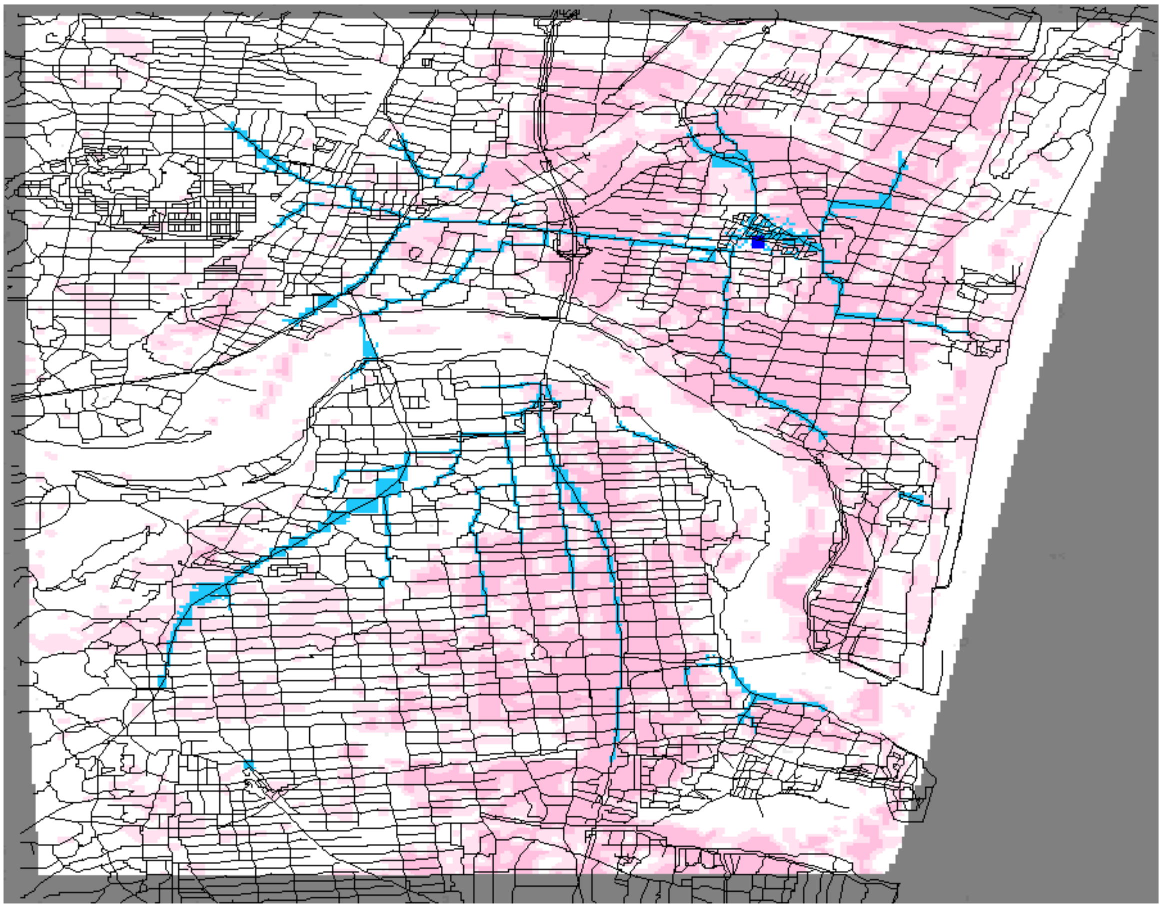


FIG. 2.5.13 Scenario A Simulation Output Statistics Graphs



OPTION B

FOOD LEFT AT END OF SIMULATION: 31

TOTAL ENERGY IN SIMULATION: 48856765

NUMBER OF DEATHS: 7408

STEPS IN SIMULATION: 865 (APPROX. 3 Days)

B

FIG. 2.5.14 Scenario B Simulation at Step 865

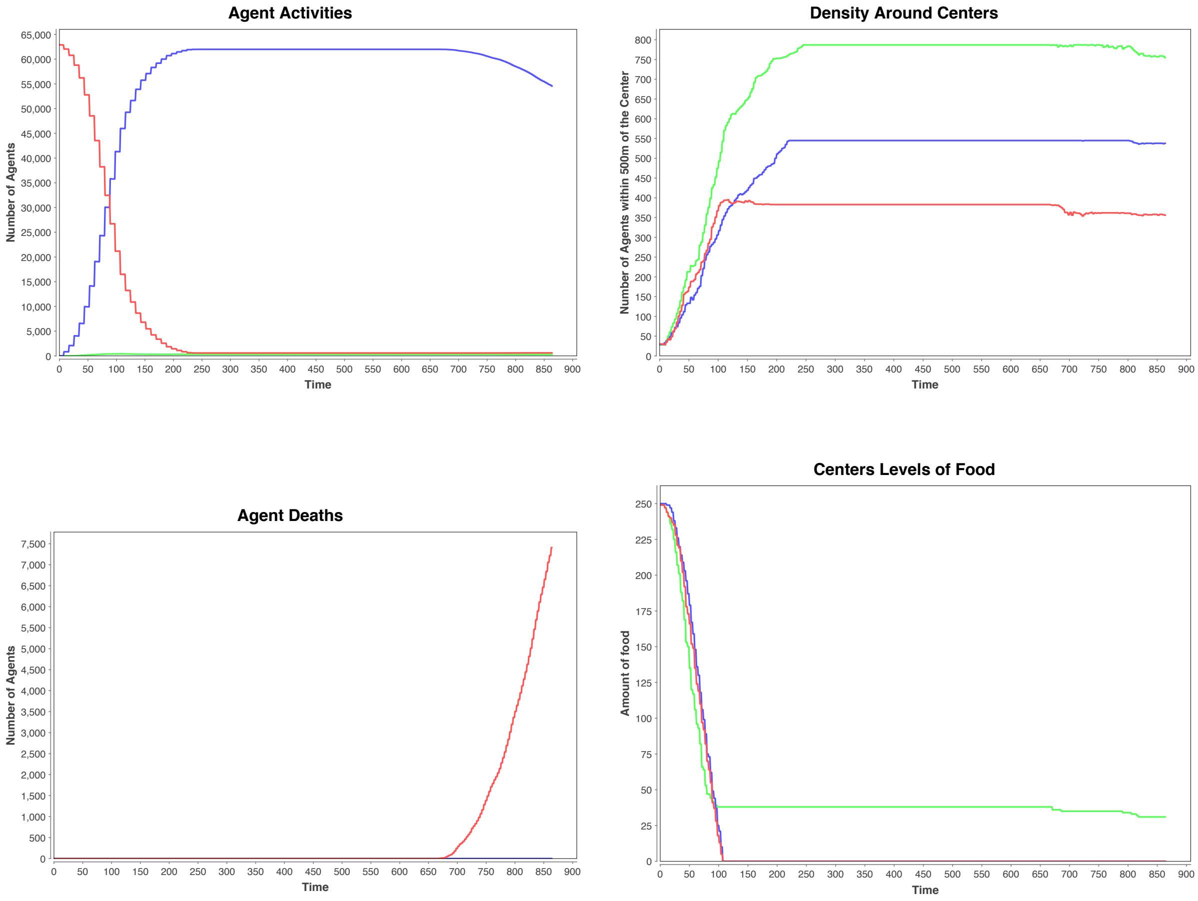


FIG. 2.5.15 Scenario B Simulation Output Statistics Graphs

DISCUSSION & CONCLUSION

DISCUSSION & CONCLUSION

Given the broad scope of the work explored in this thesis, it is not surprising that many technical and conceptual limits are hit throughout, and that as a result, certain simplifications and assumptions have been employed to circumvent these limitations, in the interest of cycling through a full implementation of the proposed framework. Similarly, a range of considerations presented themselves throughout the exploration, which might be useful as alternative lenses through which the framework might be viewed in any future use or development of it. This section offers both insight and expansion on some of these issues.

DISCIPLINE SPECIFIC EXPERTISE

A primary limitation faced in this work, concerns the way in which extra-disciplinary strategies, methods, techniques and tools might be employed within the framework. As described in Part 1 of this work (See Ch. 1.3), the framework is conceived of as a black-box system, such that a broad range of mechanisms can be employed to fulfill the aims of each framework phase. This aspect of the framework design is very much intentional, and conceived of as a strategy for responding to the multivariate, and multi-scalar nature of complex territorial systems (See Ch. 1.1). As such, the inclusion of extra-disciplinary strategies, methods, techniques and tools remains integral to the design of the framework. However, the specific role of the architect or designer in implementing such a broad range of devices within the framework requires some consideration.

Within the design experiment presented in Part 2, various approaches to appropriating extra-disciplinary devices were explored. For instance, during the *discovery* phase, each process was conducted first hand, beginning with raw data, and working through a variety of extra-disciplinary methods from start to finish (See Ch. 2.2). On the other hand, the model explored in the *modelling* phase, and deployed in the *exploration* phase was developed by discipline specific experts as a tool to be used by a range of researchers within their own work (See Ch. 2.3).

A primary consideration in choosing between such approaches, of course, concerns the time in which such activities can take place. Admittedly, researching and conducting such work from scratch can prove detrimentally time consuming, as experienced in the *discovery* example cited above. Yet, beyond the time it takes to learn and explore these methods, there is a broader concern that there is a risk these devices will be misused or that the results produced will be misinterpreted, as a consequence of having been employed without an adequate disciplinary foundation.

Within the work that comprises this thesis, this limitation was acknowledged, and a decision to explore extra-disciplinary methods, techniques and tools was embraced, as an opportunity to develop a basic literacy within these domains. However, even with such a mandate, it ought to be recognized that incorporating a more specific mechanism for consulting disciplinary experts within the utilization of the proposed framework would be of great benefit to the process overall.

SUBJECTIVITY IN MODELLING

While developing computational models from the ground up is a significant task, which poses limitations as described above, appropriating models developed entirely by outside authors also calls forward some important considerations. Primarily, the subjectivity which guides the conceptualization of a model, and the inherent assumptions which underlay its construction deserve much consideration.

For instance, consider the "hierarchy of needs" which lays at the foundation of the model used in this work (See Ch. 2.3). Though it may be an appropriate conceptual basis for such a model, it carries with it a set of assumptions about population dynamics that remain up for debate. For example, considerations might include whether such a model foregrounds self-interest over cooperation and collaboration, and the broad range of subtle variations that can exist within a population in this regard. With this in mind, care and due diligence are required in selecting and appropriating a model, particularly if it is to be employed as a black-box device.

Further to this notion is a consideration of the nature in which such models are employed. Simulation can be utilized as a performance based mechanism for optimization, but it can also be used as a mechanism for design exploration. With this in mind, the value of simulation with respect to the complex territorial systems considered in this work may be more about identifying otherwise invisible opportunities than about arriving at optimal outcomes; an argument which is consistent with the discussion of complex territorial systems considered in Ch. 1.1.

RECURSIVE ABSTRACTION AND IMPLEMENTATION

As suggested earlier in this thesis (see Ch. 1.3), the framework proposed and explored in this work is conceived of with a potential for recursive implementation in mind; a process inspired by a foundational strategy in computer science known as *recursive abstraction*. Here, *recursion* refers to a method of problem solving where the solution to a complex problem relies on solving incrementally smaller instances of the same problem, where the smallest instance of the problem is referred to as the *base case*.[1]

Similarly, *recursive abstraction* refers to a process in which abstractions are incrementally layered to create larger and larger systems, allowing focus to be directed toward each layer of abstraction individually, as well as its relationship to adjacent layers.[2] In computer science, this forms a basis for software development, where the *base case* 1's and 0's, or *bits*, that underlay every operation in computing, can be successively abstracted into larger and larger procedures, such that programmers using "high level" languages, need not ever deal with them directly.[3] With this in mind, recursive abstraction is, ultimately, a strategy which is capable of effectively managing multivariate components and multi-scalar conditions within both the representation and design of complex systems, whether they be complex software systems, or complex territorial systems.

In the context of this work, the proposed framework operates as a base case, or base unit, as it has been referred to throughout this text (see Ch. 1.3). While this thesis has been an exploration of this base unit framework (See Part 2), the intention is that in future research,

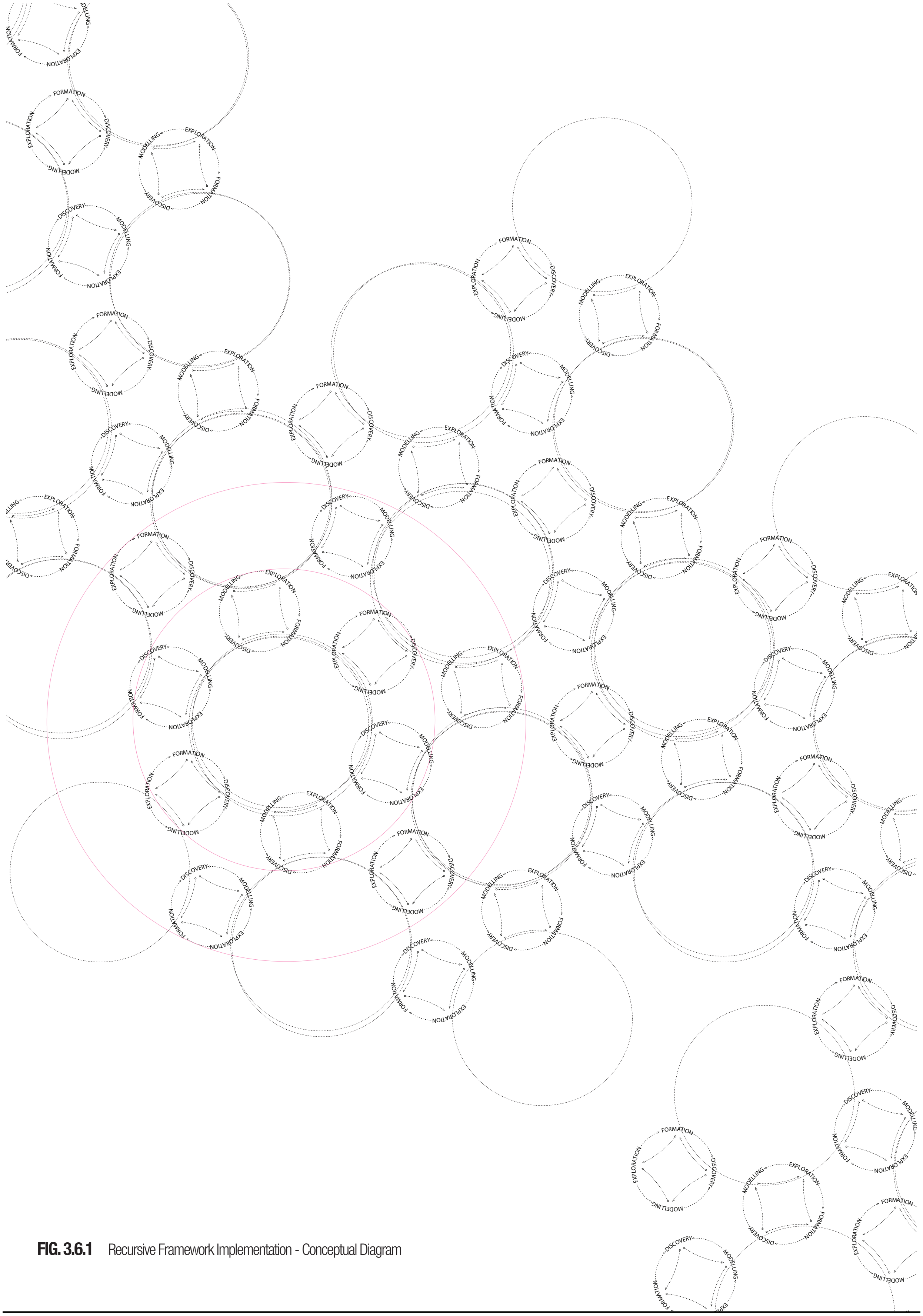


FIG. 3.6.1 Recursive Framework Implementation - Conceptual Diagram

starting with a single instance, implementations can be incrementally layered, to gradually build a greater and greater representation of system complexity within a territorial design process.

Using the 2011 Japan earthquake and tsunami test case explored in part 2 as an example, the framework might be implemented recursively in a number of ways, such that greater degrees of relevant complexity are reflected in the design response. For instance, the implementation explored in part 2 is centered on a computational model developed within the field of computational social science, which drives a simulation of social response to the installation of aid distribution centers throughout the region, and suggests how this might affect population health in the aftermath of the crisis (See Part 2). As such, this implementation of the framework only addresses a very small component of what might be considered within such a large rehabilitation effort.

Springing from a number of points in this first framework implementation, a range of additional implementations could take root. For instance, the characterization of the disaster scenario, as established during the *discovery* phase (see Ch. 2.2), could serve as a basis for a number of other computational models which require a characterization of the conditions on the ground, such as ecological or agricultural models which might deal with implications of habitat destruction.

Similarly, a range of extra-disciplinary devices might be utilized to construct supply-chain models which consider the specific mechanisms by which aid supplies are obtained, stored, transported, and distributed, as well as costs associated with doing so.

In this way, clusters of models, which can be developed and implemented in isolation, can, operating in conjunction, contribute to a collective representation of contextual complexity. As the representation of complexity increases in degree, so does the potential for anticipating emergent and epigenetic potentials (see Ch. 1.1). Subsequently, with such a recursive implementation, the agency of the framework as an aid for territorial design & decision making has the potential to greatly increase.

CONCLUSION

Through the proposition and exploration of a methodological framework which operates at the intersection of territorial design research and computational thinking, this thesis has explored ways in which contextual complexity can be effectively carried through a design process. Moreover, as explored in Part 2, each phase of the framework effectively offers an opportunity to engage key qualities of open, complex territorial systems (as described in Ch. 1.1).

As an opportunity to investigate complex territorial resources and constraints, the *discovery* phase directly engages the multivariate and multi-scalar conditions which characterize open, complex territorial systems, creating a robust data environment which can operate as an active agent in the phases that follow. This was explored and exemplified in the design experiment presented in Part 2, through the acquisition of contextual data, and preparation of the population grid, road network, damage map and priority regions map, which were carried through as inputs to both the *modelling* and *formation* phases that followed.

The *modelling* phase, set out to develop a dynamic representation of the principal relationships and interactions which comprise a territorial system, extends the representation of multivariate and multi-scalar components and conditions established during the *discovery* phase, by situating them within a model which will structure the principle environment for design exploration. Accordingly, in the framework implementation explored in Part 2, the damage map, population grid, and road network are used to structure the environment of the agent-based model which drives the *exploration* phase that follows.

As the principle forum for design decision making, and the generation of design iterations, the *formation* phase also takes inputs from the *discovery* phase, further extending the representation of complexity initially mapped and explored. Again, exemplified in Part 2, the damage map and priority regions map were used as the principle drivers of

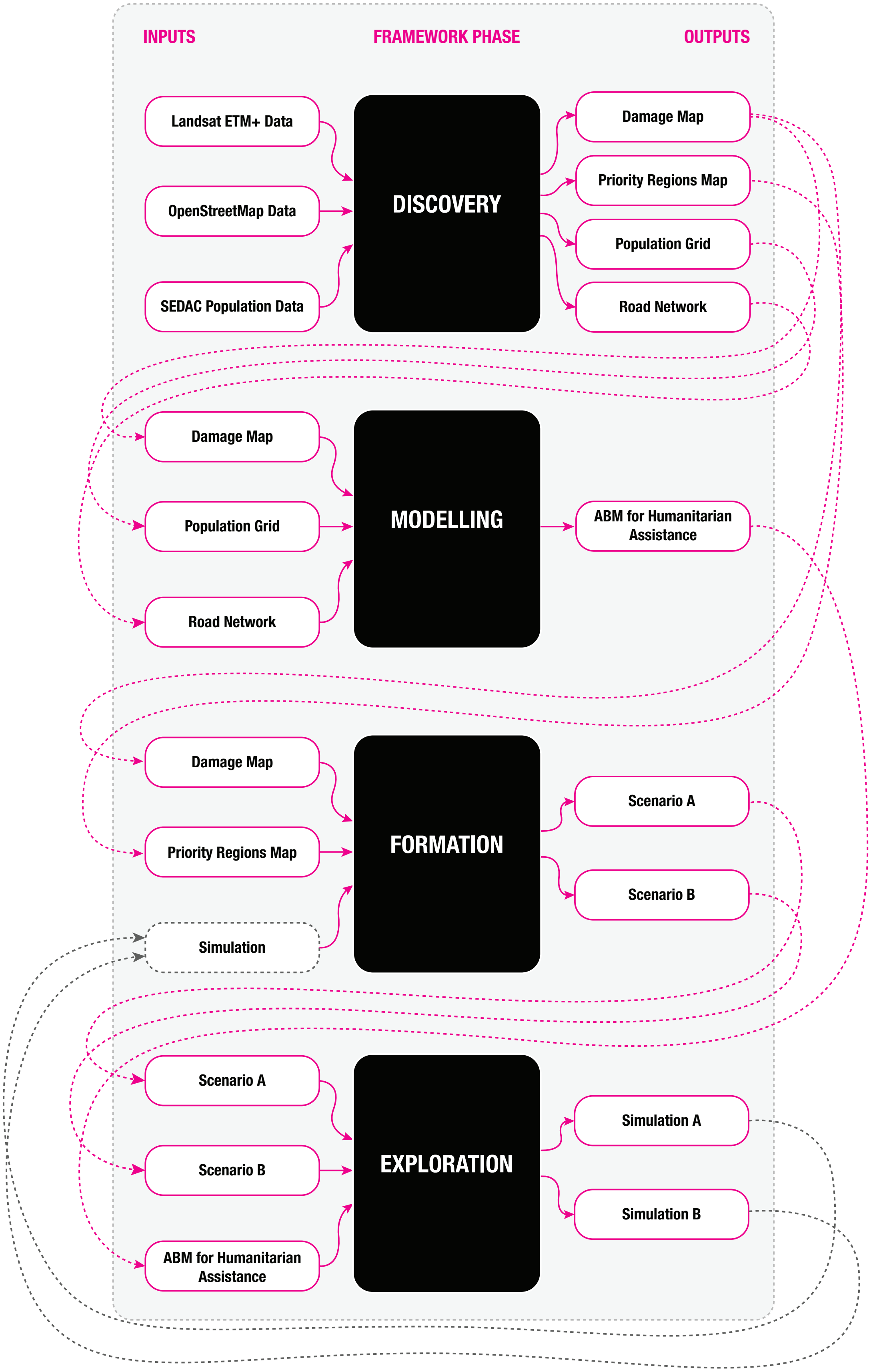


FIG. 3.6.1 Framework Data Path and Process Chain

design decision making in the establishment of aid distribution network scenarios A and B, which are utilized in the *exploration* phase that follows.

Finally, extending the opportunity to explore the emergent and epigenetic potentials which a design intervention may incite on its context, the *exploration* phase offers a platform for a design iteration to become an active component within the previously developed system model. Once again, exemplified in Part 2, the agent-based model developed during the *modelling* phase, and the design iterations, Scenario A and Scenario B, proposed during the *formation* phase come together within the simulation that drives the *exploration* phase. Within Part 2, the *exploration* phase was only employed to the extent that the operation of the model and simulation could be verified, however, it can be extrapolated that with further exploration of the simulation results, the outputs of this phase could be passed back to the *formation* phase to inform future design iterations, as the structure of the framework would typically suggest.

While this process only represents an initial investigation of a single implementation of the proposed framework, the successful transposition of the original characterization of complexity between phases experienced during Part 2 of this work suggests some progress in managing complexity within a design process was made, as this work initially set out to do. Yet, the many challenges and limitations that were encountered throughout the work, particularly surrounding the manner in which a designer might employ extra-disciplinary strategies, methods, techniques and tools suggests that much research within this domain remains.

Fundamentally, if a recursive implementation of the framework, as described above, is to become a practical reality, the effectiveness and efficiency with which such extra-disciplinary methods, strategies and tools are used within its black-box phases requires much attention. With that in mind, any future success in the development of the framework rests on developing stronger mechanisms for the incorporation of domain specific expertise, and further consideration of the specific roles and skills required of the designer within such a process.

ENDNOTES

1	Procedures and the Processes They Generate, 1996
2	Wing, 2006, p. 1
3	Wing, 2006, p. 1

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