ICLEI Local Governments for Sustainability

7th Global Forum on Urban Resilience & Adaptation

Bonn, Germany 6 - 8 July 2016

Resilient Cities 2016

Session E3: Novel data and spatial analysis tools to inform resilience planning and urban development

A novel GIS mapping tool for urban and critical infrastructures resilience management

Ehimen, E., Sweeney, J., Dowling, C., and Hynes, W.,

Abstract: Modern cities and urban societies are highly dependent on the services provided by critical infrastructures (CIs). The critical functions of these CI systems must therefore be guaranteed even in the face of probable and unforeseeable threats. Various resilience strategies and frameworks have been proposed and discussed to meet this goal. There is however a lack of practical tools utilisable by CI or oversight bodies to properly monitor and manage resilience in their critical systems. This paper describes a multi CI, non-scenario specific- GIS based tool which can be used by CIs and urban stakeholders for effective resilience management. The tool presented in this paper addresses the need for tools to support the operationalisation of resilience concepts. The mapping function afforded by the tool provides the ability to have an overview visualisation of all physical sub-components and assets of an investigated CI system or organisation based on scores obtained from resilience assessment method which incorporates considerations from the societal, organisational and technical resilience domains. The CI stakeholders using the tool will therefore be able to view their current scores as well as determine their minimum and target resilience levels. Important system interdependencies with other CI systems will also be highlighted as well as the societal impacts of the potential failure of an investigated CI asset.

Keywords: Critical Infrastructure, Geographic Information Systems (GIS) Mapping, Resilience Management

1. Introduction

Critical infrastructures (CIs) provide essential functions and services that support societal, economic and environmental systems. As both natural and man-made threats, disaster and crisis situations become more common place, the need to ensure the resilience of CIs so that they are capable of withstanding, adapting and recovering from adverse events becomes paramount. This is especially important in the context of preserving and maintaining the continuation of the services and products they provide. Against this backdrop, the application of practical resilience approaches for all manner of disasters and threats are required to ensure that the basic functions and structures of the CI are guaranteed with supply continued with minimum disruptions. This is especially important due to the increasing system complexities and interdependencies associated with current CI systems, where the cascading effects from the breakdown of one system on other interconnected systems could significantly affect public safety, security, economic activities or environmental quality of their coverage areas, and in turn could negatively affect the overall wellbeing of the affected societies. To facilitate an understanding and foster the adaptation and uptake of potential resilience management strategies in the operational activities of CIs, different resilience management methods and quantification approaches have been put forward in the literature (i.e. Hosseini et al, 2016; Lebaka et al, 2016; Emery & Schulman, 2015, van der Vleuten et al, 2013; Wu et al, 2016). A current review of the state of the art with respect to CI resilience management highlighted a lack of standardised resilience management approaches in CI systems, with traditional risk assessment more widely utilised. More practical management systems which can be easily employed by CI to achieve their intended resilience goals are therefore needed. The work presented in this paper describes a practical GIS based mapping tool which addresses the desires of CI stakeholders and is applicable for the monitoring of the resilience level of CI systems.

1.1. Need for Operable Resilience Focused Tools

A survey which targeted relevant stakeholders from CI (carried out by the EU RESILENS project, grant no 653260) examined the practical understanding of resilience in CI processes, investigating methods and tools used in practice (if any) to facilitate resilience management; the drawbacks of such tools; and the expectations and functionalities that the CI stakeholders require from resilience tools. The survey findings showed that while CI stakeholders have a growing appreciation of the concept of resilience, they currently lack practical tools for monitoring, quantifying and scoring their levels of resilience, with current methods used mainly in line with "traditional" probabilistic risk assessment and management practices. A key requirement desired by CI stakeholders (and also relevant public oversight bodies and end-users in the urban sphere) was the need for the inclusion of a GIS (geographic information systems) component in any potential resilience management tool which will be developed to be adapted and operationalised in the CIs. Such resilience mapping is hoped to extend current GIS tools used by the CIs for spatially visualising, monitoring and managing disruptive events and their impacts on the CI operations and service delivery, as well as for analysing the recovery of the affected regions after the event.

In order to achieve this goal, several GIS based resilience management tools have been proposed. However, these tools can be best described as "spatial risk vulnerability" tools since they are mainly designed to address probabilistic risks (i.e. regions which are floods prone), and are usually scenario and sector (or installation) specific, aiding an identification of strategies which would be employed to manage the physical and societal aspects in the case of occurrence of those risks. While the vulnerability identification and management functions such tools provide are very useful, they are however restrictive in their functionality as resilience management tools. This is especially prevalent as such tools cannot be used to properly address the system complexities especially with regards to the interdependencies between CI and the urban environment in general. This is due to the emphasis current probabilistic risk tools put on the physical domain, without incorporating organisational, societal and information domains.

The GIS tool put forward here was designed to fully incorporate multiple CI sectors, which is especially important for visualising the interconnectivities of CI systems and the potential cascading consequences of a particular CI failure. Furthermore, in addition to the physical aspects of the CI system, other domains (i.e. organisational, societal, information and environmental) which are usually not covered in existing risk based mapping tools were considered in the developed tool. The novel GIS based tool developed uses a non-scenario specific methodology to visualise the "resilience levels" of different levels of the CI systems (i.e. overall system level, sub-systems, or specific CI assets or installations).

2. Methodology: CI Resilience Evaluation and Mapping Tool

2.1. The CI Resilience Assessment function

Prior to a visualisation of the resilience status of the CI systems, a methodology to evaluate the resilience levels of the investigated CIs is initially required. Here, a semi-quantitative method was deemed useful as the basis for a suitable CI resilience assessment method since this would provide tangible metric based results that would be appreciated by the mainly technical CI stakeholders, while being robust enough to capture organisational and societal considerations which are important when addressing CI resilience. A semi-quantitative based "*Critical Infrastructure Resilience Assessment Tool - CI-RAT*" which views the CI's resilience preparedness as the totality of different defined system components and interactions proposed by the RESILENS project was developed to meet this goal (RESILENS, 2016). The assessment components and items in the CI-RAT incorporate the two resilience qualities of systems: inherent (functioning during normal operation, non-crises periods) and adaptive (response flexibility capacity during disaster/disruption processes) capacities. To index the CI resilience using the tool, relevant assessment criteria (using a Likert type assessment criteria scale of 0-5) linked to the component items which are reflective of the current state of the CI system are then selected and constitutes the resilience score for that item. The CI-RAT is comprised of 53 resilience evaluation questions which uses a grouping of time dependent resilience stages/phases (requisites) as the basis for examining the different resilience related issues in the investigated critical infrastructure assets, systems or organisations. An overview of these requisites and the issues covered in them using the CI-RAT tool are provided in Table 1:

Table 1. CI-RAT Resilience Requisites and Components

Requisites	**Resilience Components and Issues Covered**
Requisite 1	
Prepare, Prevent and Protect	Organisation and co-ordination
	Identification, analysis and management of current and future risks
	Budget allocation for CI protection, redundancy and resilience enhancement and the organisation's financial capacity
	Responsiveness - incident response and business continuity planning
	Safeguarding CI assets with electronic and physical means
Requisite 2	
Mitigate, Absorb & Adapt	Building codes and infrastructure hardening
	Robustness of communication networks, mission critical systems, power / energy supply, supply chain and core services
	Early warning and information management systems
	Immediate actions
Requisite 3	
Respond, Recover and Learn	Responsiveness - exercises for identified potential emergencies, disasters, crises and unexpected events
	Resource capability of labour and incident response capacities
	Resource capability of engineering equipment, communication means, welfare and relief equipment and command and control necessary during incidents
	Funding resources availability
	Learning from others

After using the CI-RAT, the CI stakeholders are presented with the overall scores associated with their CI resilience, allowing the CI operators to appraise their current resilience status with regards to the different resilience domains and requisites (stages).

2.2. The GIS Mapping Function

The GIS mapping tool primarily serves as a visualisation function linked to the outputs of the CI-RAT tool, utilising the obtained score to provide a hot-spot indication of the resilience levels of investigated CI assets or systems in a given geographical area. The Mapping tool is therefore intended to assist the CI stakeholders to have a better overview of the resilience of their systems leading to a clearer understanding of potential impacts of disruptions of evaluated critical assets, as well as aiding in an overview visualisation of any available system interdependencies associated with the evaluated CI.
Initial inputs are required to afford the proper functioning of the mapping tool. These are aimed at extracting specific details of the investigated CI (including its name, physical address and brief overview), its critical functions, number and location of the critical assets and system sub-components and the geographical boundaries of the CI system and/or assets. The relationships with other CIs (service supplies and dependencies) are also acquired at this stage.

The study then employs data obtained from the open data source, Open Street Map (https://openstreetmap.org) and used this as the basis of the mapping data and method used to geographically locate and visualise the initial inputs provided earlier. The open source mapping platform, Mapbox (www.mapbox.com) was further used to aesthetically refine the derived maps. A geographical overview of the resilience status of the particular investigated asset, assets or CI system is represented using a pre-defined colour coding system associated with the resilience score. The colour coding is drawn from an aggregation the overall resilience score and represents the resilience status of the evaluated CI system and is based on the percentage overall resilience score obtained for the investigated CI using the CI-RAT. An overview of the colour code system used for identifying the resilience status of the CI systems in the GIS mapping tool is presented in Table 2.

Table 4. Colour coding used for indicating the resilience levels of investigated CI assets.

Resilience score (%)	100-80	80-60	60-50	50-40	40-30	30-20	20-10	10-0
Colour code								
Designated status	Excellent	Very Resilient	Resilient	Average	Resilience enhancement required	Urgent enhancement required	Poor	Very Poor

The geographical boundaries of the tool are automatically defined on the basis of capturing the locations of the investigated CIs and interdependent systems. In addition to the overview visualisation of the different CI assets in a given geographical area (Figure 1), the description and individual resilience score of specific assets can be further identified (Figure 2). A function which visualises the existing interdependencies with other CI systems function is also included in the mapping page (Figure 3). Furthermore, incorporating useful population data from available sources (i.e. through central statistics offices) in the mapping tool provides the ability to be able to estimate the potential impact of the critical service disruption on the society based on an indication of the geographical area covered by the CI asset or system.

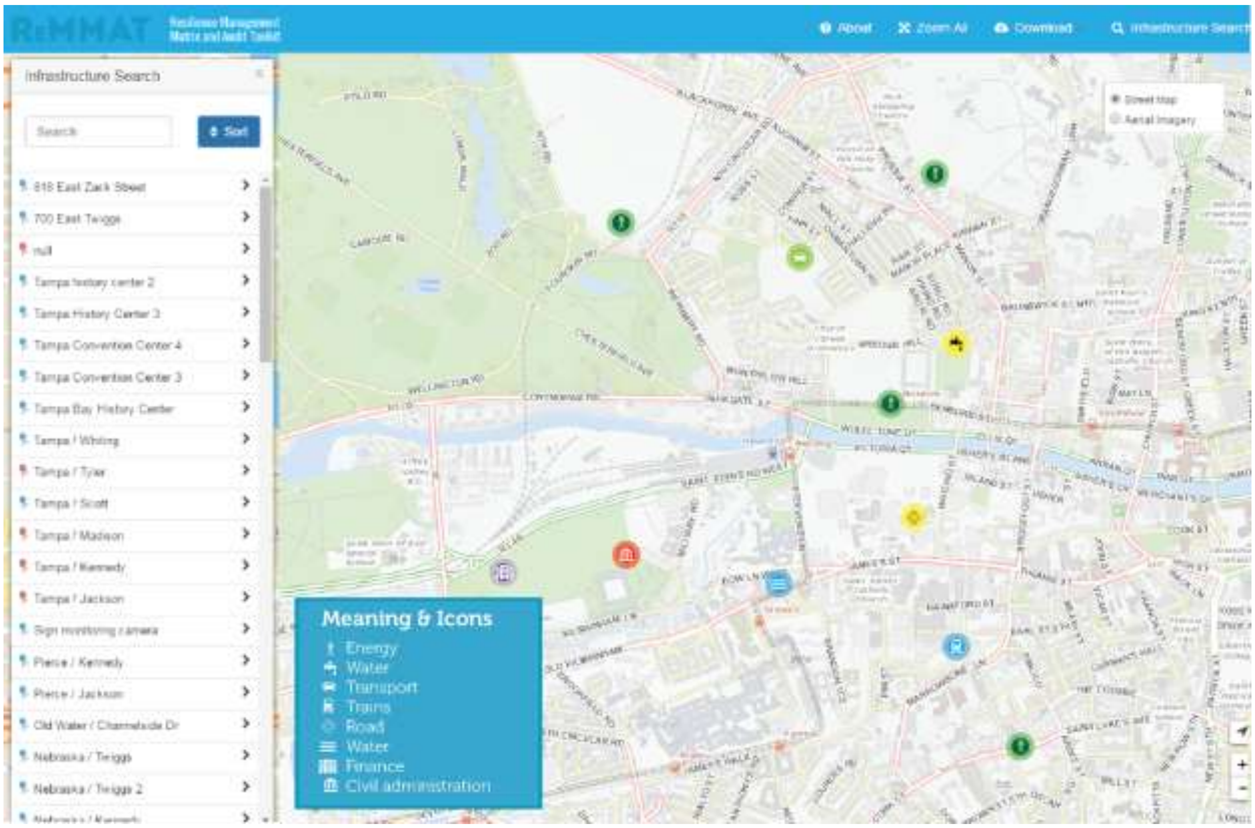

Figure 1. Sample screenshots of the colour coded resilience status of CI assets in the GIS resilience mapping tool.

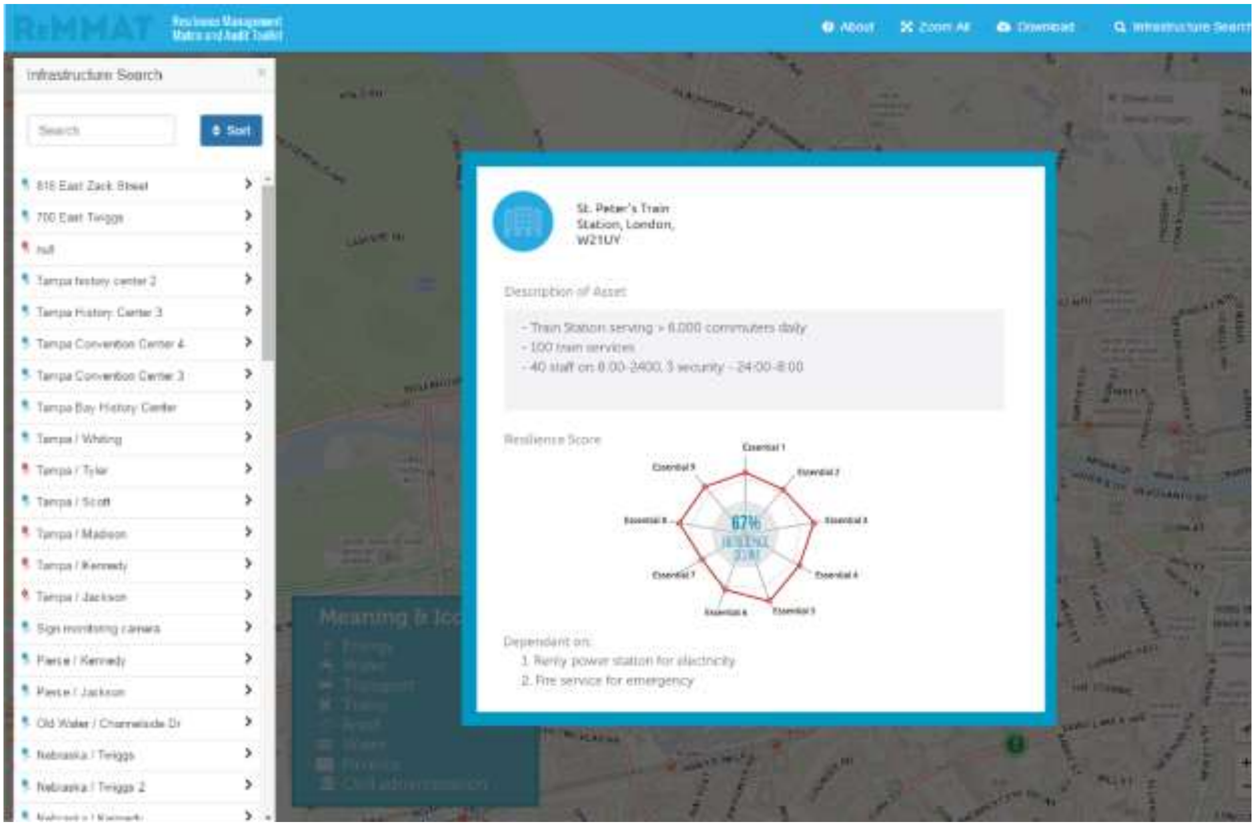

Figure 2. Screenshot of the overall resilience score for an investigated CI in the GIS mapping tool.

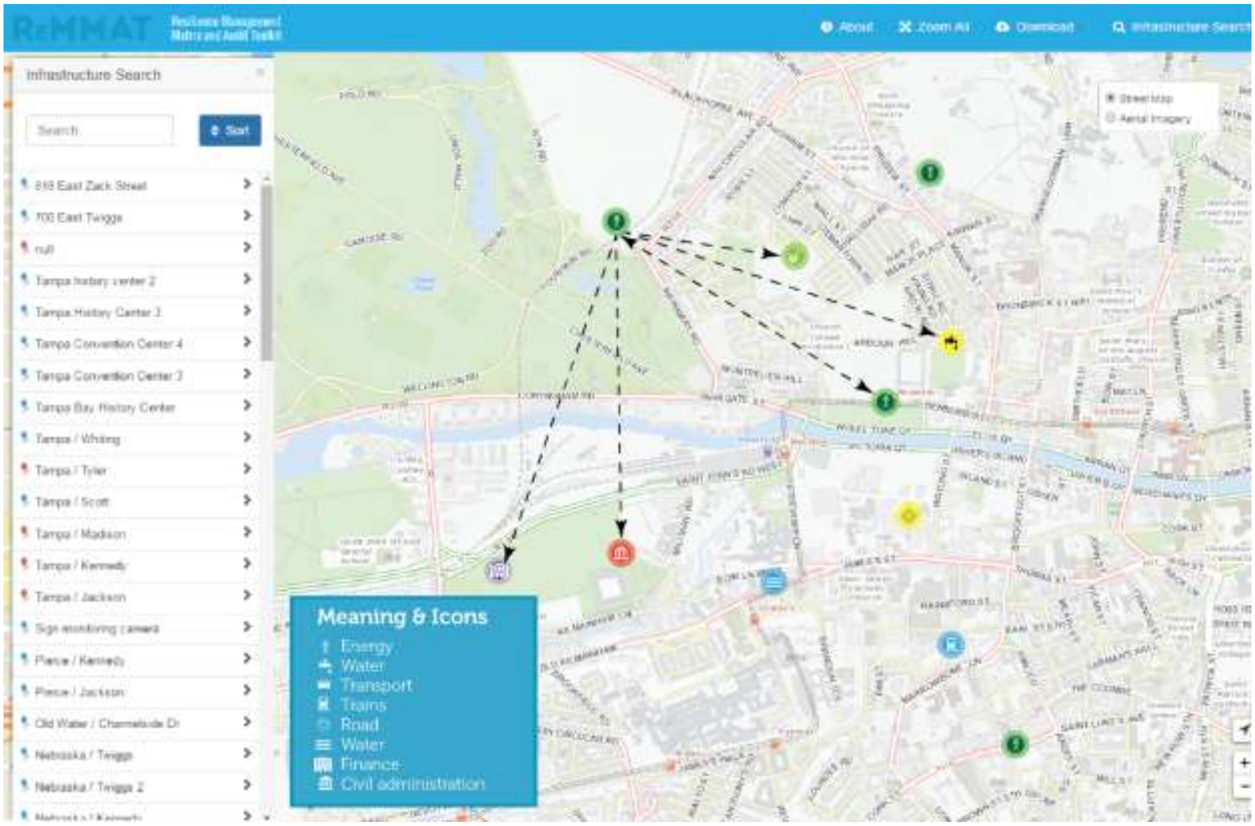

Figure 3. CI system interconnectivities

3. Applying the GIS Based Resilience Evaluation and Visualisation Tools

The evaluation and GIS tool have been developed and digitised into a web-based tool called the Resilience Management Matrix and Audit tool which is accessible online at http://resilens.leute.server.de/ci-rat/. Log in details for the online tool can be obtained from the tool developers from the EU RESILENS project and the paper authors.

3.1. Using the Tool - CI System Level

The online evaluation and mapping tool is expected to be a valuable, operable resource primarily aimed at allowing CI owners and operators have a better appreciation of how resilient their entities are to potential disruptions (man-made or natural). The GIS functions of the tool provides a visual representation of the resilience status of the investigated system allowing the CI owners and operators easily locate the assets in their systems which could be improved further. With regards to successful application, the evaluation tool and the accompanying GIS mapping tool are considered to be best completed at the asset level of the investigated CI system. Here, respective line managers for the different assets or sub-components of the CI system respectively complete the evaluation and mapping tool for their assets. The individual resilience scores for the respective assets can then be aggregated and visualised using the

GIS mapping functions. Using this scheme, the CI owners and operators can then have a visual overview of the “weak-spots” with regards the component assets in their systems on the basis of their scores.

3.2. Using the Tool – Oversight Agencies, Urban and Emergency Response Bodies.

The tool also has application for relevant policy developers, first responders, civil protection personnel and wider societal stakeholders which are concerned with societal continuation and ensuring that the critical service provision are guaranteed and face minimum disruption after a natural or man-made disruption event. The outputs of the tool could therefore be used to provide an oversight on the preparedness to probable and unpredictable risks of the CIs under their custody, and can inform decision making on the impacts of CI failures on the urban environment and how best to respond. The tool is therefore considered to be best used by such agencies by requesting that the CIs under their coverage individually use the tool and then provide the resilience scores and the details of the investigated assets to the oversight or emergency response agencies. Such agencies would therefore have a very high level overview of all the assets and systems resilience levels and the interdependencies available in their spatial coverage area. However, in practice unless there is a legal backing for this, this might be difficult to accomplish, since a trust system will need to be in-place before such information (which will be considered as highly sensitive) by the respective CIs can be shared.

4. Conclusion

The GIS based non-scenario specific resilience management tool presented in this paper considers the physical, organisational, societal and information domains to obtain a semi-quantitative resilience score for an investigated CI. The tool spatially maps the resilience levels of CI assets and interdependencies which might be available with other CIs. Furthermore, the development of an application programme interface (API) results in the protocols and outputs of this tool being easily integrated into existing GIS mapping tools which are already in use in CI systems.

References:

Emery, R., and Schulman, R. (2015). Comparing Emergency Response Infrastructure to Other Critical Infrastructures in the California Bay-Delta of the United States: A Research Note on Internal-Infrastructural Differences in Reliability Management. *Journal of Contingencies and Crisis Management* 23, pp 193-200

Hosseini, S., Barker, K., and Ramirez-Marquez, J.E. (2016) A Review of Definitions and Measures of System Resilience. *Reliability Engineering and System* Safety 145, pp 47-6.

Lebaka, L., Hemantes, J., and Sarriegi, J.M. (2016). A Holistic Framework for Building Critical Infrastructure Resilience. *Technological Forecasting and Social Change* 103, pp 21-33.

RESILENS (2016) Deliverable 2.1 (D2.2) Qualitative, Semi-Quantitative and Quantitative Methods and Measures for Resilience Assessment and Enhancement. Version 2. Report and Templates. Report submitted to the EC. Accessible from http://resilens.eu/resilens-outputs/

Wu, B., Tang A., and Wu J. (2016) Modelling cascading failures in interdependent infrastructures under terrorist attacks. *Reliability Engineering and System Safety* 147, pp 1-8.

Acknowledgements:

This research was supported by the work carried out as part of the EU RESILENS project “Realising European Resilience for Critical Infrastructure”, Grant no 653260. We are thankful to our RESILENS consortium colleagues who provided expertise that greatly assisted the research, although they may not agree with all of the interpretations provided in this paper.

The author(s):

Dr. Ehiaze Ehimen
Senior Researcher
Future Analytics Consulting Ltd
Email: ehiaze.ehimen@futureanalytics.ie
Www: http://futureanalytics.ie/

James Sweeney
Senior Associate
Future Analytics Consulting Ltd.
Email: james.sweeney@futureanalytics.ie
Www: http://futureanalytics.ie/

Conor Dowling
PhD Researcher
Future Analytics Consulting Ltd
Email: conor.dowling@futureanalytics.ie
Www: http://futureanalytics.ie/

Dr. William Hynes
Managing Director
Future Analytics Consulting Ltd.
Email: william.hynes@futureanalytics.ie
Www: http://futureanalytics.ie/

Bio:

Dr. Ehiaze Ehimen

Dr Ehiaze Ehimen is currently the Senior Research coordinator at Future Analytics Consulting. He has an extensive project management and research experience in European programmes and is currently actively involved as the Technical coordinator for the H2020 RESILENS project, which is developing tools to enhance the operationalisation of the resilience concept in critical infrastructures (CI). Prior to joining FAC in 2015, he worked as a principal investigator, researcher and task lead contributors to several EU and national energy and bio-processing related projects.

James Sweeney

James Sweeney is a Senior Associate at Future Analytics Consulting. He is a chartered planner with Masters degrees in both Regional and Urban Planning and Geographical Information Science and has demonstrated experience in detailed socio-economic analysis, spatial analysis and economic research. He is particularly versed in developing urban strategic plans and the use of demographic analysis in forecasting future population projections

Conor Dowling

Conor Dowling is a PhD student working with Future Analytics as part of an employment based research programme. His research includes the development of resilience measures for critical infrastructure systems. Conor has worked on several EU FP7 and H2020 resilience related projects including the RESILENS project.

Dr. William Hynes

Dr. William Hynes is a Chartered Town Planner and a Chartered Surveyor, and a founder and director of Future Analytics Consulting. William has extensive experience providing expert advice to public and private sector clients in the areas of strategic spatial planning including at national, regional, county and local levels, demography, housing and economic analysis and forecasting that is fully integrated with spatial planning, health planning, retail impact assessment and infrastructure planning.