Virtualis
Social, Spatial and Technological Spaces in Real and Virtual Domains
SpatialTrain III

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Formosa, Formosa Pace, Sciberras

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SpatialTrain III

Edited by
Saviour Formosa, Janice Formosa Pace, Elaine Sciberras

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Schools of thought abound
Researchers seek
Policy Makers Make
Decision takers Take
But Implementers are Few

The publication is testament to
Researchers who sought to implement
A rare breed indeed

To them we dedicate this publication
as an achievement of boundless
effort to affect and effect change

I wanna feel sunlight on my face
I see that dust cloud disappear without a trace
I wanna take shelter from the poison rain
Where the streets have no name, oh, oh

U2
The Joshua Tree - 1987

ACKNOWLEDGEMENTS

Thanks goes to all those who made this book happen, the Planning Authority, the University of Malta, the ESF mechanism through the Planning and Priorities Co-ordination Division (PPCD), the different entities who partook to spatial information during the past decades striving to push GIS to its fruition. In conjunction with SIntegraM, a sister ERDF project, SpatialTrain sought to deliver the training and research component in a veritable adventure aimed at bringing together all-spatial data related entities within one single data transfer and sharing core, whilst identifying those knowledge lacunae and morphing it to ensure delivery in governance, operational functionality and academic research within a central GI core.

This publication, whilst published under the SpatialTrain umbrella, posits an academics' and functionalists' publication effort that provides solid research and real-world studies. It posits the basis for research studies and scholarly work whilst keeping the societal requirements in vista.

Thanks goes to the authors who dedicated the past years towards the target to further spatial information through educational and operational outputs. This publication resulted from a drive to fund studies at graduate and postgraduate levels, information on which is found in the First Volume of this trio of publications entitled "Pathways to Spatial Cognition: A Multi-Domain Approach - SpatialTrain I", as well as the Second Volume entitled "Applied Geomatics Approaches In the Maltese Islands - SpatialTrain II".

- The papers in this publication span diverse domains. The Domains include:
- Spatial Technologies: GI and its real-life application;
- Project based Approaches: Benefits gained from National, EU and International Projects;
- Thematic: Environmental, Social and Development Planning Domains; and
- Emergent Realities: Virtuality, Augmented Reality and Innovation.

The authors deserve a thanks for the papers researched for this publications: Gianmarco Alberti, Argyros Argyridis, Mario V. Balzan, Oshri Baron, Marc Bonazountas, Brian Borg, Trevor Borg, Floor Brouwer, Tony Cassar, Alex Borg Galea, Mark Bugeja, George Buhagiar, Fabrizio Cali, George Chalaris, Evangelos Chalkiadakis, Laspidou Chrysi, Ugo Cortesi, Alexiei Dingli, Frank Farrugia, Saviour Formosa, Janice Formosa Pace, Charles Galdies, Timmy Gambin, Reuben Grima, Stephen Grixti, Ashley Hili, Omar Hili, Despina Kallidromitou, Lydia Lyroudia, Wendy Jo Mifsud, Tram Thi Ngoc Nguyen, Andrew Pace, Vasiliki Palla, Maria Refalo, Giorgio Saio, Elaine Sciberras, Dylan Seychell, Cecilia Tirelli, Nicholas C. Vella and Koen Verberne.

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Thanks to all for making this process a reality.

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Andrew Pace. Dr. Pace is a Principal Officer in the Digitisation Department of Heritage Malta, the national agency responsible for museums, conservation practice and cultural heritage. He is developing the agency's collection management system, being launched in 2023, which will provide a publicly accessible portal to access information and images of the national inventory held by Heritage Malta's museums and sites. He has previously worked for the British Library in digitisation and cataloguing, has coordinated international research projects with IASA and UNESCO, and on a Leverhulme funded digital repatriation project of early ethnographic indigenous audio recordings in Oceania. Locally, he is a founder of the community archive project Magna Żmien and has undertaken surveys to establish a national inventory of audiovisual media in Malta with the M3P Foundation and National Archives.

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Maria Refalo graduated in the Geographic field, shares interest in physical geography with respect to geospatial reference. Graduated in 2012 from the University of Malta with a B.A. Honours Degree in Geography after a three-year course which included both human and physical exploration of the Maltese geographical islands. Her undergraduate thesis entitled, "Distribution of marine algae along the coastline of the Maltese islands in relation to environmental factors", scrutinised the development and actuality importance of algae species around the coast of the two main islands of Malta and Gozo, whilst observing the environmental effects incurred to their natural habitat. She read for a Post Graduate Certificate in Education and graduated again from the University of Malta in 2013 as a Geography Teacher. Following Ms Refalo's interest in Geographical Information Systems (GIS) she opted for a career in the GIS field. Subsequently, in 2017 she graduated with a Masters in Applied Geographical Information Systems at the Manchester Metropolitan University. Her study focused mainly on the GIS analysis of the three pillars of risk incorporating the National Flood Relief Project (NFRP), the study entitled "An investigation of surface water flooding and social vulnerability in Malta". She has been working at the Planning Authority since 2015 engaged in various analysis through the application of GIS.

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Elaine Sciberras. Dr. Sciberras holds a Doctorate and Masters in Geographical Information Systems and Remote Sensing from the University of Cambridge, U.K and a B.Sc. in Biology and Chemistry from the University of Malta. She has worked for several years in the private sector with informatics and GIS companies. She has lectured on environmental applications of remote sensing and GIS at the University of Malta. She has also worked as an FP7 evaluator with the European Commission's Research Executive Agency. Since joining the Planning Authority (previously MEPA) in 2007, she has worked on various Geomatics projects involving various spatial data analysis, national spatial outputs for the European Environmental Agency (EEA), publication of research papers and project management of EU-funded projects. These included being Project Leader for part of MEPA's ERDF156 environmental monitoring project and more, recently, the Project Leader of the PA's ESF.04.071 SpatialTrain Scholarships Scheme. She is Malta's lead delegate for the European Commission's Space Programme Committee for the Copernicus Configuration and the Copernicus User Forum, the GEO European High Level Working Group and the Principal Contact Point for the EEA's EIONET Malta Land Systems group.

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Cecilia Tirelli. Dr. Tirelli research in Remote Sensing is focused on the study of atmospheric constituents: aerosol and gases (SO2 and CO2 in particular). She worked with on ground active (LIDAR) and passive instruments detecting in the VIS/TIR part of the electromagnetic spectrum and in the analysis of active and passive multispectral and hyperspectral satellite. Her research topics are the aerosols microphysical and optical properties retrieval and simulation in urban and rural environments; the study of aerosols role in the atmospheric correction of satellite data; the CO2 retrieval from satellite measurements. During the PhD she carried out a study for the realization of a complex system of multispectral (MFRSR) and multiangular (Bistatic Lidar) remote sensing measurements in the city of Rome for the characterization of urban aerosol microphysical and optical properties and vertical distribution in the boundary layer. As a research fellow, she worked on the development of algorithms for the study of the dependence of optical particle sizers (OPCs) measurements on the aerosol microphysical properties for the comparison with aerodynamic particles sizer measurements with the aim of the characterization of Saharan dust intrusions in the boundary layer. She also worked on activities for development and application of radiative transfer models to passive remote sounding of the Earth's atmosphere from space and high-altitude platforms. Recently she started to work on CO2 retrieval from satellite. As PhD student and research fellow she was involved in national and international research projects supported by EU, ASI, and PNRA.

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Nicholas C. Vella. Professor Vella is an Associate Professor of Mediterranean Archaeology in the Department of Classics and Archaeology, University of Malta. His current research focuses on the history of archaeological practice in the Mediterranean. He has been involved in the ERC-funded FRAGSUS project, leading the researchers from the University of Malta, participated in excavations and undertook the ethnographic work in Malta and Gozo that informed the work presented here. He is also the Director of the University of Malta's Doctoral School.

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Koen Verberne has a Master of Science in Business Administration, a Master of Arts in philosophy, and a Bachelor of Science in Cultural Anthropology Experiences. Since March 2014 he is the owner of DataCraft. DataCraft helps companies in the field of Earth Observation and geo-information services with business development, innovation management, project management and strategy. During 2009 -2014 he was working with Airbus Defence & Space; space company in the Netherlands Business developer as a project manager and innovator for Earth observation services, Corporate strategist and change manager, and Contracts officer for multiple space projects. Since 2011 he is the co-owner of MoodyDoodle. MoodyDoodle is a story telling company for children/ youngsters and their parents. Our activities motivate children to think creative about all kinds of subjects (bees, literature). Since 2011 PhD student at the Open University. Subject: Complementary Currencies.

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PROLOGUE

The SIntegraM and SpatialTrain Initiatives

Elaine Sciberras and Ashley Hili

Introduction

The publication trio stems from the activities related to ERDF and ESF funding, through two projects entitled SIntegraM and SpatialTrain, distinct but complementary projects that enabled the spatial technology and capacity fulcrums to combine.

The SIntegraM initiative

The ERDF.02.030 SIntegraM project was co-financed by the European Union and the Government of Malta, in accordance with the rules of European Structural and Investment Funds 2014-2020 Operational Programme 1: "Fostering a competitive and sustainable economy to meet our challenges". The full name of the project was ERDF.02.030 SIntegraM - Developing Spatial Data Integration for the Maltese Islands.

This project aimed to develop and implement a national spatial data infrastructure and enhance the capacity of geo-spatial/GIS technology expertise for the Maltese Islands. It constituted the creation of a strategic approach to spatial data, creation of critical base datasets, as well as enabling a legislative and mentality shift in terms of exchange and access to data. The project ensured that the underlying aerial, terrestrial and marine infrastructure and knowledge gain was made available to all government entities in order to deliver the relevant analytical framework as per national, EU and other international obligations and requirements. The infrastructure and range of systems, equipment; analytical and dissemination tool/s were geared to enable inter-governmental data dissemination, knowledge gain and an integrated approach towards information foresight.

The main activities of this project consisted of the following:

- Basemap creation, which includes data acquisition of imagery, LiDAR, infra-red and other technologies;
- Development of a strategy for NSDI, legislative drivers, identification of spatial data flows, drafting of protocols for data and information exchange based on a common approach to the data cycle and the drafting of policy for the free exchange

of data across the governmental entities;

- Re-Projection Tool across all governmental entities;
- Acquisition of systems for the management of spatial data (software) and analytical tools (predictive tools, immersive environments) for thematic and spatio-temporal analysis;
- Dissemination tool for the distribution and reporting of data to the public, scientific domains and EU/International reporting;
- Media Train for publicity and dissemination;
- Acquisition of equipment: core Infrastructure, aerial-based technologies, terrestrial-based technologies, marine-based technologies and spatial lab enhancement.

Results

The project achieved the following results through its focus on an inter-entity drive.

A unified approach to spatial information, ICT and technologies as delivered through the inter-entity review, analysis and development of a Strategy for NSDI, inter-linked Legislative Drivers review and changes and the identification of inter-entity spatial data flows was achieved. The initiative ensured that all entities are brought on board and bureaucratic issues and information-barriers are reduced through an integrated drafting of protocols for data and information exchange based on a common approach to the data cycle. Such include the drafting of policies for the free exchange of data across the governmental entities, knowledge again, access to ICT knowledge and ICT technologies as well as a national process enabling one unified and integrated information structure.

All government entities have access to the national basemap free of charge as against the current system where each department would have to acquire a license and in turn cross-charge the mapping agency for other services rendered. The creation of the basemap, which also includes data acquisition of imagery, LiDAR data, oblique imagery, infra-red data and other technologies reduced the need for multiple data capture and expenditure by different departments as well as disseminate the resultant knowledge to all other entities, ensuring a smooth upgrading of both the affectivity and efficiency with regards to information and implementation processes. The project ensured that time wastage and process redundancies are eliminated through the activity that target the reprojection of all spatial data from the previous 1988-induced non-earth projection that was slowing down the data process as well as causing major capacity issues through a cross-departmental process to reproject all datasets to a real-world map.

Services rendered through the project that encompass all entities detailed with spatial information will be delivered through the acquisition of systems covering the management of spatial data (basic and advanced software tools) as well as the acquisition of highly advanced analytical tools targeted for real-time systems and real-life investigation. This will be made possible through the setting up of a collective system of processes, software and hardware that ensure that entities are equipped with predictive tools, analytical models as well as immersive environments. The latter functionality equips inter-departmental and inter-disciplinary focus teams to interact in real and virtual worlds ensuring that instant decision-taking is made possible through scenario building or instant access to streaming information.

The project in turn helped improve inter-departmental efficiency services through ICT as it delivered a dissemination tool for the distribution and reporting of data to the public, scientific domains and EU/international reporting structures. In turn, this eased pressure on inter-departmental work, as information would be instantly available through an online system both for the public and service personnel who carry out fieldwork, data capture through to the implementation of services on-the-ground and remote sites.

The one concept established a reduction in public spending whilst ensuring a national approach to inter-departmental efficiency as related to the acquisition of equipment that will be used by all entities through a time-slotted process, which process ensured that high-priority activities such as emergency services would be given precedence to ongoing projects or ad hoc initiatives. Such systems included ICT infrastructure that was comprised of immersive environment technologies, aerial-based technologies such as drones and specialised cameras (IR, thermal, LiDAR, RGB), terrestrial-based technologies that aimed to scan streets, infrastructure, buildings and underground facilities, land survey and GNSS/GPS/GPR technologies as well as marine-based technologies. As the Lead partner, the Planning Authority implemented the project in collaboration with all the ministries and other stakeholders.

The SpatialTrain initiative

The parallel capacity building ESF project was entitled SpatialTrain. The use of spatial data, along with the technologies used to capture such spatial data, is growing steadily due to the diverse applications of geographic information (GI). This has been the case within the Maltese public administration and its various entities. Each entity has diverse roles and obligations for data monitoring and analysis, reporting at both the local and EU level, policy making, simulation studies and the development of information systems. The use of spatial data is key to achieve these objectives within sectors such as cultural heritage, infrastructure and planning, environmental monitoring, public health and social well-being, amongst others. Such data can range from national digital basemaps, satellite imagery and aerial orthophotos to high precision datasets obtained through specialised data acquisition techniques using Unmanned Automated Vehicles (UAVs) and lidar scanners, as well as cloud technology and Artificial Intelligence (AI). The range of data that can be acquired is vast and the technology used to acquire and analyse such data is growing at a rapid pace. A significant portion of such high-end technology has been acquired through EU-funded projects, such as the Planning Authority (PA)'s ERDF.02.030 SIntegraM project - Developing Spatial Data Integration for the Maltese Islands and its predecessor, the ERDF 156 project - Developing a national environmental monitoring infrastructure and capacity: shifting the state of access.

Following the investment in both GI data and technologies, the efficient use of both within the public administration is crucial to sustain the investment in the long-term. The human capacity element is an important asset to maximise the use of the GI. Therefore, training of the public administration in the field of geomatic is key. This was the drive behind the PA's SpatialTrain Scholarships Scheme initiative which provided specialised tertiary training in the field of geomatics to the Maltese public administration.

The ESF.04.071 SpatialTrain Scholarships Scheme project was part-financed by the European Union – European Social Fund (ESF) under Operational Programme II – Cohesion Policy 2014-2020, "Investing in human capital to create more opportunities and promote the well-being of society". It provided the human capacity and expertise to upgrade the knowledge base in the use of geospatial technology as part of the development of the national spatial infrastructure within the public sector.

Specialised Training provided

Training was provided in a coherent manner and aimed to tackle various thematic areas respective to the remits of the different entities. Topics aimed to train staff on the principles of Geomatics, the use of GIS, as well as its applications to the various fields which would complement the roles of various government entities. These included data gathering and outputs with respect to bathymetric modelling, environmental risk assessment, public health spatial dimension, planning and infrastructure management, cultural heritage risk management, spatial information systems and crime mapping amongst others. Therefore, the target was to offer training opportunities to staff with basic knowledge on the use of geomatics as well as to staff who already deal with spatial data but would need to specialise in more detailed analysis and data modelling.

Four MQF levels (levels 4-7) of training in the field of Geomatics (spatial data) were offered in SpatialTrain's scholarship scheme. Level 4 (Certificate) and Level 5 (Diploma) training was provided as dedicated courses provided by a local contractor. Level 6 (Bachelors) and Level 7 (Masters) scholarships were offered to participants who could choose their own specialisation geomatics course. In such cases, their research focused on thematic aspects relevant to their line of work within their respective public entity.

Project implementation

SpatialTrain scholarships were open to applicants who were employed within the public sector or public service and had obtained official endorsements to participate from their relevant Ministry. A Project Monitoring Board of Review (PMBR) was set up to review the selection process and the implementation of the training process of the successful applicants throughout the duration of their scholarship period. A monitoring mechanism involving mandatory reporting was also put in place.

Uptake of scholarships was multi-disciplinary over all four MQF levels and ranged from a broad range of public entity sectors involving 15 different entities. The participants' knowledge varied from those who had no prior use of spatial data/ Geographic Information Systems to others who planned to expand their knowledge of spatial data to tackle in-depth applications of geomatics. Apart from course work, each participant was required to work on a dedicated research project whereby spatial data was applied to a specific application context. These included applications in the fields of spatial planning and land use, infrastructure and safety, cultural heritage, public health, crime spatial dynamics, water and marine applications, ecosystem monitoring, spatial data infrastructures and web GIS portals.

The SpatialTrain Scholarships Scheme project was a first major step at a local level to provide accreditation of the public sector within the field of geomatics. However, this should not be the last. The technology in the field of geomatics is growing rapidly as is the awareness to rely on spatial data to address key issues such a climate change, public health, security, and data sharing and harmonisation, both at national and EU levels. This should provide the impetus to ensure that dedicated training initiatives in the geomatics sector will continue to be essential within the public administration.

INTRODUCTION

Virtualis and Spatial Information? The What Factor

Saviour Formosa

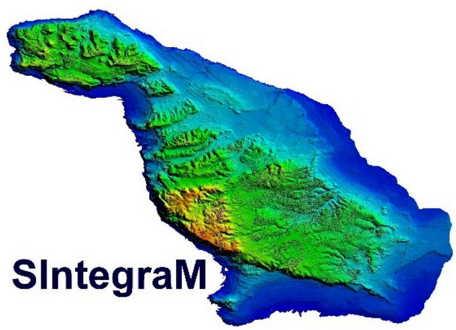
The Digital Transformation of the Real World entails the need to move from analogue to digital to virtual in an attempt to recreate that reality into a digital twin that is enhanced through multi-domain, multi-disciplinary integration systems. The What factor in the W6H model (What, Why, Who, Where, When, How and Why Not) takes central stage in this publication through the plethora of research studies that pivot around the location kernel. The past two decades have been dedicated by scholars and in turn society to employing a bottom-up approach to the concept of **digitisation** and **digitalisation**. Through data, information and in turn knowledge, action can now be taken up by policy-makers and decision-takers to ensure that all are ready for a new research and analytical operand: an operand that pivots on the Digital Transformation through strategic, operational and tactical activities as the fourth industrial revolution takes hold (Lachvajderova at al (2021); Vrana et al, (2022).

Jason Bloomberg in 2018 (Bloomberg, 2018) attempts to dissect the foundations and perils that this concept is fraught with. In essence, these can be condensed into:

- Digitisation is the process of *converting* analogue into digital format.
- Digitalisation focuses on the *adaptation processes*.
- Digital Transformation is the *process of acquiring knowledge* from the data into information for future action through creative means.

Malta's attempts for Spatial Digital Transformation were achieved through many projects and three dedicated ones entitled ERDF156 (PPCD, 2014), SIntegraM (Planning Authority, 2012) and SpatialTrain (European Commission, 2019).

Elaine Sciberras and Ashley Hili in the prologue discuss the dual projects SIntegraM and SpatialTrain, ERDF and ESF projects respectively, which have enabled the transformation of the geographical information systems landscape in the Maltese Islands and globally. The EU-funded projects have enabled the public service and sector to partake to hardware, software, processes and methodologies across the entities. Most importantly, however, was the value-added gained through collaboration, knowledge sharing, data integration, multi-disciplinary approaches and inter-domain knowledge exchange. The concept went beyond data sharing but delved into hardware sharing and in turn, knowledge and action actuation. The ongoing collaboration with international players, as evidenced in this publication resulted in veritable new levels of capacity and structural change.



This publication is the result of decades of collaboration in the academic, operational and strategic domains as exemplified by over 40 authors, each an established researcher in their own domain. What they succeeded in doing, is the bringing together of a diversified approach to integrative efforts for the spatial and virtualization resultant from the GI-based approach to spatial relationships to integration and immersion.

The publication contains twenty-four chapters authored by the SIntegraM and SpatialTrain project contributors: a tsunami of information gleaned from data and in turn knowledge readied for positive action in the physical, natural and social environments. The publication which is the third of three books is categorised in four domains: Spatial technologies: GI and its real-life application, Project based Approaches: Benefits gained from National, EU and International Projects Domain, Thematic: Environmental, Social and Development Planning Domains, Emergent Realities: Virtuality, Augmented Reality and Innovation Domain. As in all three publications, such chapters can be recategorised by method, delivery, analytics and other facets, each sustained by the other domains as they seek fruition towards integration and eventually wellbeing.

Note: the three publications are to be referenced as follows:

- Formosa, S., Sciberras, E. & Bonazountas, M., (Eds). (2022). Pathways to Spatial Cognition: A Multi-Domain Approach - SpatialTrain I, Planning Authority
- Formosa, S., Sciberras, E. & Galdies, C., (Eds). (2022). Applied Geomatics Approaches in the Maltese Islands - SpatialTrain II, Planning Authority
- Formosa, S., Formosa Pace, J. & Sciberras, E., (Eds). (2022). Virtualis: Social, Spatial and Technological Spaces in Real and Virtual Domains - SpatialTrain III, Planning Authority

Pivot I: Spatial technologies: GI and its real-life application

The first section focuses on five themes that lay the foundation for geographical or spatial information science and systems as used in the real-life applications. The topics cover archaeology, environmental management, urban redevelopment, land cover and the geodatabases that permeate this technology.

Chapter 1 by Gianmarco Alberti, Reuben Grima and Nicholas C. Vella state that Geographic Information System is today extensively used for the analysis and interpretation of social science data. In particular, with its ability to acquire, to meaningfully organize, and to integrate heterogeneous spatial information in a common analytical framework, GIS proves crucial to understand the mutual relation(s) between human behaviour and the surrounding environment. With few ground-breaking exceptions, mainly framed in the context of archaeological research, GIS and quantitative methods have not been used so far in Malta to better understand the development and layered making of the landscape in relatively recent historical times. The present work aims at describing the main achievements of the authors' research (developed in the context of the five-year ERC-funded FRAGSUS project) into the Maltese economic and historical landscape and will provide insights into how modern GIS-based quantitative approaches can be used in conjunction with qualitative data (for instance, cadastral maps and ethnographic accounts) to shed light on human-environment interaction in Malta during the last two centuries.

Brian Borg and Omar Hili in Chapter 2 tackle the understanding and use of a proprietary geodatabase; the Esri Enterprise Geodatabase, focusing on the potentials and resource utilities of such database and common uses with-in today`s Industries. The study provides a brief explanation of what is and ESRI enterprise Geodatabase and how such a database is used in day-to-day custom systems to provide rapid and effective geospatial data to users and quick query results for Management decisions in Governmental organizations. The Water Services Corporation (WSC) is the entity responsible for the water management of the Maltese islands and has much of its operations based on the field. This essentially means that the majority of the corporation's assets and operations have a spatial context so rationally a strategic decision was taken to implement and place geographic information systems (GIS) in the centre of other major information systems within the corporation. Following the need to implement an enterprise GIS, the corporation invested in one of the leading GIS products and eventually implemented all the encompassing products. These products consisted mainly an enterprise geo-database, GIS specialised servers and desktop applications required for the proper maintenance and analysis of GIS data. Furthermore, the WSC's Strategic Information Directorate (SID) managed to set up a team of software developers which were specifically trained to develop GIS centric software capable of seamlessly integrating other systems and solutions.

Frank Farrugia in Chapter 3 posits that urban areas are dynamic systems. The heterogeneity of various factors such as proximity to open spaces and commercial areas, influence urban redevelopment and determine the urban morphology. A combination of GIScience, urban planning and computational modelling can identify the driving factors attracting redevelopment and simulate and predict redevelopment patterns. GIScience has emerged as the science that can help planners to analyse spatial information during the planning process. The aim of this study is to use GIS and agent-based modelling to simulate urban redevelopment potential in Malta. The first objective to fulfil this aim is to analyse redeveloped sites within the urban areas and establish the most influential zoning factors that attract redevelopment. The second objective is to develop (design and translate into a computer code) and implement the rules of an Agent-Based Model driven by the identified factors in objective one to simulate and observe the emergent behaviours of urban redevelopment. To model this spatial urban redevelopment, particular emphasis was given to three Local Administrative Units (LAUs) in Malta, which are Gozo and Comino, Northern Harbour, and Southern Harbour. 9,535 approved planning applications for redevelopment or conversion between 2007 and 2018 were analysed.

Chapter 4 by George Buhagiar and Alex Borg Galea investigate the notions of integrated environmental management (IEM), hailed as a road towards sustainability, which are shaped by political and cognitive rationales for integration and offer a well-founded logic, as experience shows how fragmented approaches commonly shift problems or create new ones, instead of solving them. Identifying and overcoming fragmentation in either the political or cognitive sphere is challenging. The chapter focuses on overcoming cognitive challenges to IEM, through planning with appropriate remote techniques, using two local cases studies of valleys and coastal erosion areas, where the inherent nature of the resources managed makes integrated data acquisition difficult. Safeguarding the intrinsic values of valleys and their service to human well-being demands an integrated management approach. Malta's hydrologically transient valleys, with intermittent and ephemeral hydrological behaviour, pose major challenges to understanding the fragile eco-hydrological interactions comprehensively. Mitigation of risks to safety in coastal erosion areas requires close investigation of changes, often traceable only from inaccessible or precarious locations. A major challenge is data availability covering space and time adequately, to enable detection and modelling of change processes, with prediction in advance of the point when a coastal location becomes a hazard. However, despite the small geographical scale, progress is impeded by difficulties in data acquisition, due to inherent characteristics of coastal and valley resources. We argue that planning for remote sensing techniques is key to overcoming cognitive challenges of extensive data acquisition, required to meet specific management needs to virtually: characterise, map, model, monitor and eventually predict processes and changes in the real world.

Elaine Sciberras posits an interesting study in Chapter 5 on the European Commission's Copernicus programme. This is a user-driven programme of Earth observation utilising satellite and in-situ observations servicing a range of applications. Sentinel-2 satellite data has various applications for land and marine monitoring due to its multispectral and temporal capabilities. Malta participates as part of both the Copernicus Network Relay and the Copernicus Academy for the promotion of the Copernicus programme. With respect to the spatial dimension of the Maltese Islands, the use of medium resolution satellite data, such as Sentinel-2 data, is expected to have specific applications which contribute to existing and future high-resolution data available for the Maltese Islands. This paper showcases the availability of data from the Copernicus program, as well as the use of cloud-processing and analysis tools made available through this program. This study reviews assessment of land cover in the Maltese Islands using Sentinel-2 data and classification techniques. The free and open data access of Sentinel data, as well as the high temporal resolution of such data, is deemed to be a significant factor towards assessing land cover on a frequent temporal basis. The latter also allows for the assessment of seasonal changes. The requirement to use supplementary higher resolution data, such as aerial orthophotos, for training of datasets is essential for the classification training process using Sentinel-2's satellite imagery. The high variability in land cover over the medium resolution imagery due to the presence of mixed pixels, is a significant contributor towards the production of misclassified pixels. The near-future availability of high-resolution data available through Malta's spatial data projects, together with Sentinel-2 data, will offer significant contributions towards land cover assessments of the Maltese Islands.

Pivot II: Project based Approaches by Benefits gained from National, EU and International Projects Domain

This section depicts four international project studies comprised of an international group of inter-linked scholars and researchers who developed a series of paradigms as well as a Maltese expert detailing the use of space research concepts in their strive for earth observation capacity.

Chapter 6 by Marc Bonazountas, Evangelos Chalkiadakis, Oshri Baron, Despina Kallidromitou, Vasiliki Palla and Argyros Argyridis focuses on Hero20FF's method to tackle forest fires. With the rise of forest fires in recent years, and climate change becoming a permanent and unpredictable reality, the need for solutions is growing. Once such solution is to deploy Unmanned Autonomous Systems (UAS) and Unmanned Aerial Vehicles (UAVs) to collect and provide important information for the firefighting aircrafts take-off, resources dispatching and the safety of firefighting personnel on the ground. This solution is hampered by the limitation of the UAVs which may require either a runway or a launching mechanism, making operations incompatible with fast moving fire fighting forces and manned observation towers. Hero20FF (http://www.hero20.com/) delivers a NewGen recoverable low-cost tube launched micro-UAV platform aimed to: (i) accurately estimate in real-time & measure the wind-field along an erupted forest fire, (ii) facilitate the encounter of fire rekindling, (iii) provide accurate accessibility parameters through land observation and (iv) enrich simulation scenarios with real case data. Updated and real-time produced wind maps are delivered via desktop application which extends state-of-the-technology (2017). The production is the joint effort of Uvision Ltd (Israel, https://uvisionuav.com/) and EPSILON SA (Greece, www.epsilon.gr) has been funded by the Joint Hellenic-Israel Cooperation Program (www.gsrt.gr).

Chapter 7 by Cortesi, Argyros Argyridis, Marc Bonazountas, Koen Verberne, Cecilia Tirelli and Vasiliki Palla depics that Copernicus Sentinel missions offer the capability for timely and accurate ozone concentration monitoring in the Earth's atmosphere. Ozone is the most radiatively active gas in the stratosphere, an oxidizing agent and pollutant in the troposphere, and a short-lived climate forcer. Merging of multi-source data can aid ozone monitoring. AURORA (Advanced Ultraviolet Radiation and Ozone Retrieval for Applications, an H2020 on-going project) is aimed to perform full vertical ozone profiling, through the investigation and integration of geostationary (GEO) and low Earth orbit (LEO) satellite data in different frequency ranges, and to provide atmospheric data for applications. Since Sentinel-4 and Sentinel-5 data were not available at the time of writing (2018), synthetic imagery was employed. A novel approach is investigated and developed, to assess quality of the unique ozone vertical profile obtained in a context simulating the operational environment. The method is based on a novel algorithm for the assimilation of GEO and LEO fused products. Subsequently, tropospheric ozone column and UV surface radiation are computed from the vertical distribution to focus on lower atmosphere layers. The data processing chain architecture integrates multiple virtual machines and cloud data sharing. A web portal is developed for data access and visualization. The infrastructure represents a best practice that plays a key role in ensuring wider use of Copernicus Sentinel data for academia and industry; it is the basis for a market analysis, for pre-market applications & uptake in commercial communities.

Floor Brouwer, Lydia Lyroudia, Laspidou Chrysi, Argyros Argyridis, Marc Bonazountas, Vasiliki Palla and Despina Kallidromitou in Chapter 8 focus on SIM4NEXUS's interconnections between the Nexus Components (land, food, energy, water and climate) to secure an efficient and sustainable use of resources in Europe. SIM4NEXUS enhances the integrated management of all the Nexus themes, addressing challenges such as policy inconsistencies and incoherence, and knowledge gaps on Nexus interlinkages. This is achieved by building upon already well-established models ("thematic" models simulating different Nexus components) and by developing new integration methodologies. Among others, within SIM4NEXUS innovative methodologies and approaches for integrating the outputs of the thematic models were investigated. Public domain data and metadata for decision and policy making were integrated through a GeoPlatform. Furthermore, a Knowledge Elicitation Engine was developed, integrating strategies at different spatial and temporal scales with top down and bottom-up learning process. The aim is to discover new and emergent knowledge, in the form of unknown relations between the Nexus components and policies/strategies. SIM4NEXUS creates a web-based Serious Game for multiple users, as an interactive visualization tool. This tool assists policy and decision makers in better identification and visualization of the policies at various geo-/spatial scales, towards a better scientific understanding of the Nexus. The Serious Game is developed and executed for about ten Case Studies (regional to national level) around Europe, and it is in a fast-track mode in the case study of Sardinia. Two additional Strategic Serious Games at European and Global levels are being developed for demonstration, education, and further exploitation purposes.

Stephen Grixti in Chapter 9 states that space-related technologies have nowadays permeated into our everyday lives. Amongst others, satellite Earth Observation (EO) imagery is increasingly becoming an asset to better manage and approach societal challenges in a variety of application areas. The potential of satellite EO data, can only be fully exploited by value-adding downstream services that are tailor-made to specific public and commercial needs. Such solutions, often encompassing research and development at the intersection of science and ICT, translate the unprocessed data delivered from space and other sensors into information that is meaningful to an end user. Tasked with the governance and coordination of Maltese space-related matters, the Malta Council for Science and Technology, has substantiated its awareness-raising efforts with a Space Research Fund exclusive to Maltese beneficiaries. This research programme provides financial support for research, development and innovation in the downstream satellite EO sector specifically projects that deal with the processing and exploitation of data collected through EO satellites. The programme which ran from 2018 to 2022 with yearly calls, is supported through the technical expertise of the European Space Agency and is a concrete capacity building measure within the local downstream space sector. In line with Malta's first National Space Policy, this measure provides the means for developing critical mass within the Maltese space sector. The paper provides an insight into the lessons learnt during the definition and implementation of this research programme and how such fits in the roadmap to build related capacity in Malta.

Chapter 10 by Giorgio Saio, Marc Bonazountas, George Chalaris, Argyros Argyridis, Vasiliki Palla and Despina Kallidromitou visits the formal geospatial education and training offered by European universities must be designed in line with the requirements of the private and public sector. This need led to the collaboration between academia and the private/public sector. However, a more intense collaboration and more innovative methods are necessary to cope with the challenges of the fast-evolving technological developments in the geospatial and ICT fields. The overall approach to address these objectives has been to develop new learning material and processes based on case-based learning. In the giCASES approach, enterprises and academia collaborate both when creating learning material based on real cases and during the courses (through a collaborative platform). giCASES aimed to create a repository of best practices on industry-academia cooperation for the creation and share of knowledge in the GI domain. The definition of the focus, scope and requirements of the case studies, the specification of innovative collaboration methods, with best practices on different methods and validation of these methods in different settings are also some of the expected results. giCASES also aimed to define process, tools, and methodologies for co-creation of knowledge, technical specifications for the setup of a collaboration tool (collaborative platform) and implementation of the technical infrastructure. A set of case studies adopted for case based learning and related learning material and a collaborative platform to make the results available to other stakeholders under open licenses and to attract more content providers / stakeholders to contribute to the growth of the content base are also expected.

Pivot III: Thematic by Environmental, Social and Development Planning Domains

This section depicts four thematic studies that focus on the environmental, social and development planning approaches, covering ecosystem services, heritage digitisation, community knowledge integration and social vulnerability.

Chapter 11 by Mario V. Balzan posits that the term 'nature-based solutions' has often been used to refer to adequate green infrastructure, which is cost-effective and simultaneously provides environmental, social and economic benefits, through the delivery of ecosystem services, and contributes to build resilience. This paper provides an overview of the recent work mapping and assessing ecosystem services in Malta and the implications for decision-making. Research has focused on the identification and mapping of ecosystems, and ecosystem condition, the capacity to deliver key ecosystem services and the actual use (flow) of these services by local communities leading to benefits to human well-being. The integration of results from these different assessments demonstrates several significant synergies between ecosystem services, indicating multifunctionality in the provision of ecosystem services leading to human well-being. This is considered as key criterion in the identification of green infrastructure in the Maltese Islands. A gradient in green infrastructure cover and ecosystem services capacity is observed between rural and urban areas but ecosystem services flow per unit area was in some cases higher in urban environments. These results indicate a potential mismatch between ecosystem service demand and capacity but also provide a scientific baseline for evidence-based policy which fosters the development of green infrastructure through 'nature-based' innovation promoting more specific and novel solutions for landscape and urban planning.

Chapter 12 by Tony Cassar and Andrew Pace detail a new collections management system that was introduced in Heritage Malta which will establish digital methods to bring together collections of data repository, consolidating all data covering the national collection into one centralised system. Crucially, elements of this system will be accessible to the public through a web portal. It will therefore provide both a backend platform for cataloguing objects, tracking their movement, incorporating conservation reports and other key administrative activities, and a parallel access portal to share Heritage Malta's collections online. The CMS would see the creation of comprehensive digital records for every single artifact in the collection. The work of Heritage Malta's Digitisation Department reveals how digitising cultural heritage is a multi-faceted activity that extends well beyond simply documenting collection objects. TMS and eMuseum provide the mechanisms through which these collections and media assets are documented and shared; however, workflows can also be digitised, as can auditing collections and administrative reporting.

Wendy Jo Mifsud in Chapter 13 debates how spatial planning allows for the opportunity to actively engage with society in all its complexity. This paper focuses on factors related to stakeholder engagement in practice and defines a 'theory-practice gap' between academic writings and real-life experiences of participatory planning. A case study undertaken in Malta is described, whereby participatory planning initiatives were held using a Participatory GIS platform. Three applications are contrasted in order to highlight whether the digital realm allows for improved dialogue on the environment within which we live. It is held that acknowledging the depth of value plurality in society is a route to understanding complex issues in planning. The way socio-economic factors are balanced in the quest for acting in the public interest must however reflect today's information society and the demand for legitimate representation in planning processes. Since planners are often criticised because their interpretation of policy objectives influences people's daily experiences, how can such representation directly influence the route to actionable policy? Conducting a series of participatory GIS applications has shown that representation in planning processes can be made more meaningful by providing the appropriate tools with which people can dialogue. Local communities can provide planners with in-depth knowledge that risks being lost in the search for overarching trends extrapolated externally from 'big data'. It has been found that the 'local' remains significant to the planner and that opportunities abound for increased coherence between policy and the affected communities.

Maria Refalo in Chapter 14 reviews five projects across four catchment areas in Malta that were selected as the basis for the investigation of surface water flooding, namely, Birkirkara, Gżira, Marsa and Marsaskala catchments. These catchment areas were evaluated against their hazard and susceptibility with vulnerability to flood risk within their neighbourhood. These were the same areas for which flood mitigation measures were implemented through the National Flood Relief Project (NFRP). The three pillars of risk were analysed through a mixed method approach. The public perception was evaluated through interviews with ten local council mayors and seventy questionnaires with local citizens residing in the risk zones. The responses were analysed statistically and through directional distribution analysis. Feedback obtained from both methods showed that the situation before the NFRP was at high risk. The mayors and the public imparted varying perception on the results achieved through the implementation of the NFRP. The results confirm that this study generated an accurate analysis to identify the areas of surface water flood risk. In this study, the author focused on the Marsa (Qormi-Marsa) catchment area using GIS analysis. The public perception results are briefly discussed through their respective analysis.

Pivot IV: Emergent Realities by Virtuality, Augmented Reality and Innovation Domain

The final section delves into the visualisation approach to the emergent domains that are depicted through spatial information, virtuality, augmentation and innovations. From an artistic-scientific perspective, through vehicle automation, crime and human reconstruction, this section posits thoughts for the futures that may emanate over the next months, years, decades across the physical, nature and social environments

In Chapter 15, Trevor Borg discusses 'Fungus Rock: Għerq Sinjur' (2022), a practice-based research project that brings together art and science through digital technology, combined with other more traditional media. The project takes off from the enigmatic islet in Dwejra Bay in Gozo, more popularly known as the Fungus Rock. Dating back (at the least) to the Knights of the Order of St John, fallacious stories about a rare special plant growing on the islet erroneously described as a 'fungus' (*cynomorium coccineum*) are plentiful. To safeguard what is now considered a parasitic plant the Knights of St John decreed the rock out of bounds in 1746, which remains off limits up to this day. This place-oriented artistic research embarks on a journey around the untainted rocky outcrop, in an attempt to expose some of its layers and locate them in different contexts to encourage critical discursive approaches to meaning-making. The chapter discusses how a highly accurate spatial model was 'captured' by means of a drone and photogrammetry software, that allows the viewers to explore the intricate geological and topographical features of this limestone protrusion situated a few metres away from the ecological haven in Dwejra Bay. The study considers the role of hybrid artistic practices and scientific processes in developing contemporary methodologies and creative opportunities for place-oriented artistic research.

Chapter 16 by Fabrizio Cali gives an overview of the equipment and setup available in the SIntegraM CAVE also termed the MaKS Immersion Laboratory at the University of Malta. This article describes the type of visitors and patrons of the laboratory and the presenter's approach and observations of the diverse groups. The final part explains the strengths and weakness of the different technologies as they pertain to the visitors and projects. This is provided from the perspective of a Research Officer responsible for implementing and maintaining the lab and projects, as well as presenting and facilitating its use thereof.

The next Chapter, 17 by Alexiei Dingli, Mark Bugeja and Dylan Seychell state that a critical aspect of programming autonomous vehicles is how cases, where loss of life is unavoidable, are handled. This paper outlines a study that assesses how humans would react in similar situations and hence establish heuristics that can be used in the programming of such scenarios. A set of web simulations were created that played varied scenarios revolving around the trolley problem. Participants were then asked to go through these scenarios and choose the outcome of the scenario within a limited time frame. The results concluded that a 46.8% of the people would choose to sacrifice themselves over the lives of others. With respect to decisions on the lives of pedestrians, animals and old people were least likely to be saved with the dog being killed in 54% of the times it appeared. On the other hand, children were most likely to be saved with users choosing to hit them only on 9.8% of the scenarios in which they appeared. It was also concluded that the utilitarian approach is very prevalent in this type of scenario, with the vast majority of participants choosing to save the highest number of lives.

Chapter 18 by Saviour Formosa and Janice Formosa Pace debate that for the outcomes to serve as the basis for technological change through Digitisation and Digitalisation and Digital transformation, a sound understanding of the legal, operational and informational framework is required. They state that it is necessary to push the envelope for future societal changes and its porting into digital online worlds through the study of Digitisation, Digitalisation and Digital Transformation and dedicated research in the domain. Such is feasible through a hands-on society-centric approach to the scholarly activity with a practical focus for take-up by entities, policy makers and decision-takers. Due to lacunae in the transformation process, readily-available technologies and a solid record of successes through collaboration are now a focal point for research in immersion and the capture to output process for various Maltese entities. The chapter tackles the Real-World to Virtualisation and Visualisation Processes as it delves into analytics, legislation, protection, reporting, disseminators from real-world to virtuality interactivity, digital twins, replication, innovation and immersion.

The final Chapter 19 by Tram Thi Ngoc Nguyen and Saviour Formosa, the topic of photogrammetry as used to scan a human body was taken up. The recent developments in 3D scanning technologies and immersive virtual environments have enabled idea generation and new practices in many fields including geoinformation system, archaeology, cultural heritage, forensics, game development, and more. This chapter discusses the application of photogrammetry in close-range scanning projects with a common theme of human reconstruction. In three separate projects, a skull, a face of a live subject, and a whole body of a live subject were scanned. The technical challenges are described progressively increasing with each project, that is from scanning an inanimate object to a live subject, and from scanning a face to a full body, given the constraints on budget and available equipment at our laboratory. The proposed solutions and results of these projects demonstrate that photogrammetry can be feasible for low-scale digitalisation attempts.

The epilogue by Timmy Gambin posits a case for the real and virtual worlds enhanced through the availability of tools for data acquisition, processing and sharing that have become available and are radically changing the ways we communicate with audiences interested in underwater cultural heritage. Gambin states that it is through spatial and digital data that the underwater world has become shareable and available to a global audience.

A final editorial statement for the future of such projects and studies bears an aim towards research on immersions, sensors, gaming, art, metaverses, education, medicine, societal impacts, ICT, AI-human interactivities… The field is prime for sowing.

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Pivot I

Spatial technologies: GI and its real-life application

Fusion-Lotus-Tower: AI Generated Art
AI Art App - SF

CHAPTER 1

Modern technologies, past realities: GIS-based approaches to the layered making of the Maltese landscape

Gianmarco Alberti, Reuben Grima and Nicholas C. Vella

Introduction

Geographic Information System (GIS) is a widely used tool for the analysis and interpretation of social science data. GIS provides facilities to acquire heterogeneous spatial data, to integrate them in a common analytical framework, and to meaningfully organise and interrelate spatial information (Conolly & Lake, 2006, p. 13; O'Sullivan & Unwin, 2010, pp. 22–28). The relevance of GIS to the analysis of social data rests on the obvious, yet crucial, fact that spatial data are *pervasive* (Fotheringham, Brunsdon, & Chalrton, 2002, p. 16). As a matter of fact, human beings do not act in a void, but live in and are surrounded by a physical world. Any human behaviour, be it performed either in the past or in the present, inescapably features inherent spatial components. GIS provides the proper analytical infrastructures to make sense of those spatial components by exploring, visualizing, testing, and modelling relations among spatial variables. Spatial data analysis is therefore capable to bring latent or new patterns to the fore, to get insights into spatial processes, to infer broader trends and to generalise to larger realities from smaller manageable samples in a reproducible and explicit fashion, and to ultimately turn information into useful knowledge (Baddeley, Rubak, & Turner, 2016; Conolly & Lake, 2006; O'Sullivan & Perry, 2013; O'Sullivan & Unwin, 2010; Rogerson, 2001). As such, GIS and spatial data analysis prove crucial to research fields as diverse as environment and earth science (Formosa, 2015; Tian, 2017), ecology (Wiegand & Moloney, 2014), agriculture (Plant, 2012), public health (Baluci, Vincenti, Conchin, Formosa, & Grech, 2013; Kurland & Gorr, 2014), socio-economic (Wang, 2014) and forensic disciplines (Elmes, Roedl, & Conley, 2014), crime studies (Chainey & Ratcliffe, 2005; Formosa, 2007), archaeology/anthropology (Conolly & Lake, 2006; Nakoinz & Knitter, 2016; Wheatley & Gillings, 2002).

In archaeology/anthropology, even though quantitative methods have witnessed ups and downs during the development of the discipline after the rise of the processualist approaches (Gamble, 2008, pp. 28–30; Watson, 2009), formal and explicit methodologies for data quantification and analysis are today widely used (Baxter, 1994; Blankholm, 1991; Buck, Cavanagh, & Litton, 1996; Carlson, 2017; Drennan, 2010; Nakoinz & Knitter, 2016; Orton, 1980; Shennan, 1997; VanPool & Leonard, 2010), and the analysis of spatial data is no exception. GIS is used to address different research questions in a wide variety of contexts such as the study of prehistoric travel corridors (Bell, Wilson, & Wickham, 2002; Kantner, 2004; Teeter, 2012; Whitley & Hicks, 2003), human movement and land accessibility (Byrd, Garrard, & Brandy, 2016; Contreras, 2011; Murrieta-Flores, 2012; Richards-Rissetto & Landau, 2014; J. W. H. Verhagen, Posluschny, & Danielisova, 2011), human spatial behaviours and decisions (Gorenflo & Gale, 1990), monuments visibility and inter-visibility (Friedman, Look, & Perdikaris, 2010; Williams & Nash, 2006), maritime pathways (Alberti, 2017; Indruszewski & Barton, 2006; Newhard, Levine, & Phebus, 2014), Roman aqueducts (Orengo & Miró, 2011) and roads (P. Verhagen & Jeneson, 2012), and for the prediction of the location of archaeological sites (Rogers, Collet, & Lugon, 2014; Westcott & Brandon, 2000).

The present work is framed in the context of the use of GIS and, broadly speaking, geo-spatial approaches as means to get insights into the development of the human-made landscape in Malta in relatively recent historical periods. The study rests on the research pursued by the authors within the five-year ERC-funded FRAGSUS project, which has sought to examine fragility and sustainability in small island contexts, with a focus of human-environment interactions in prehistoric Malta. As detailed elsewhere (Alberti, Grima, & Vella, 2018), one of the main objectives of our research was to focus on evidence related to the Maltese landscape in better-documented historical periods to shed light on the ways in which the landscape has been exploited and, in a broader perspective, on the determinants (either environmental or cultural, or both) of human-landscape interaction in Malta. The goal was both to enrich the interpretation of evidence dating to earlier periods and to suggest new archaeological/anthropological questions. It is worth noting that, albeit with few ground-breaking exceptions mainly framed in the context of archaeological research (Grima, 2005; Grima & Mallia, 2011), GIS and quantitative methods have not been used so far in Malta to study the development and the layered making of the landscape in more recent historical times.

While the present work describes some of the main achievements of the authors' research, it will do that from a specific standpoint. It seeks to show how GIS-based quantitative approaches can be proficiently used, in conjunction with qualitative data (for instance, cadastral maps and ethnographic accounts) (Formosa, Scicluna, Azzopardi, Formosa Pace, & Calafato, 2011, pp. 13–21), not as an end in themselves but to address specific research questions in an explicit, formal, and reproducible fashion. As a matter of fact, the use of quantitative methods allowd scientists to ask themselves if there is indeed a case to answer (Orton, 1980, p. 195). As Stephen Shennan (1997, pp. 2–3) puts it, archaeologists (and social scientists in general):

[…] must have sufficient quantitative awareness to recognise when problems arise which can be helpfully tackled in a quantitative fashion. […] in as much as all interpretation […] is concerned with identifying patterning, it can benefit from a quantitative approach. The point that […] we are identifying patterning rather than creating it is an important one […] without such an assumption […] evidence would not tell us anything […].

Research background

Our research has adopted what could be termed a retrospective view. In our opinion, insights into the subsequent evolution of the Maltese landscape may prove crucial for a better understanding of the human-landscape interaction in earlier periods for a number of reasons: first, because they form part of the same landscape palimpsest that can only be understood in diachronic terms; second, to allow more informed predictions of where evidence of earlier landscapes may be preserved; third, because different cultural responses in better documented periods may suggest new questions that may be posed to the more meagre evidence from earlier periods, and enrich their interpretations.

At the outset of our research, two broad overarching research questions were elicited. The first was to formally assess the existence (if any) of either environmental or cultural (or both) determinants of agricultural productivity in Malta before heavy mechanization. While the existence of those determinants can be postulated from a theoretical point of view, as studies in other geographical contexts show (e.g., Akıncı, Özalp, & Turgut, 2013; Prishchepov, Müller, Dubinin, Baumann, & Radeloff, 2013), no such attempt had been previously done for Malta. The second, intertwined, research question regarded shedding light on the way(s) in which other forms of economic exploitation, such as herding and animal husbandry, related to the agricultural landscape, to other forms of human economic investment in the Maltese landscape, and to actual evidence on the ground.

It is worth noting that different types of data constituted the building blocks of our research. On the one hand, qualitative data were available to us. These comprised information about land agricultural quality and location of farmhouses embedded in mid-1800s cadastral maps, collectively called *cabrei* (Ginori Lisci, 1978), access to which was kindly made possible by Dr Charles Farrugia (CEO and National Archivist, National Archives of Malta). Also, ethnographic data regarding movements of flocks across the Maltese landscape were collected by one of us (NCV) from interviews of local shepherds.

Other information, qualitative in nature even though stored in GIS format, have been manually acquired from a body of different cartographic sources (Alberti et al., 2018): for instance, the location and extent of geological layers; the layout of the 1800s road network; the extent of the 1800s urbanized areas; the location and extent of the so-called "public spaces" (wasteland); the extent of different soil types across the entire Maltese landscape; the location of springs; the extent and location of parcels featuring different agricultural quality (manually extracted to GIS from the above-mentioned *cabrei* maps).

On the other hand, quantitative data were also available for this study. These comprised Light Detection and Ranging (LiDAR) data and orthophotos acquired in the context of the European project ERDF156 *Developing National Environmental Monitoring Infrastructure and Capacity*, which were made available by the former Malta Environment and Planning Authority (MEPA), with the kind assistance of Prof Saviour Formosa and Prof Timmy Gambin, both from the University of Malta. LiDAR data proved crucial for many aspects of our research because they provided the basis to build a fine-grained Digital Terrain Model (hereafter DTM) for Malta. This, in turn, allowed to calculate different landscape geomorphological characteristics used in our GIS-based analyses, such as slope, aspect, topographic wetness index, terrain planar and profile curvature. Other quantitative information was derived from the qualitative data to which reference has been made above, such as the distance from the 1800s road network, from the coast-line, from the major geological fault-lines, and from the 1800s urbanized areas.

From the preceding description, it should be apparent how our research entailed from the outset the stimulating challenge of handling, integrating, analysing and making sense of a large variety of data. A particularly challenging aspect was the devising of a strategy to transfer the important information on land agricultural quality stored in the *cabreo* maps from the realm of qualitative data to that of quantitative information. This required a tailor-made methodology to be developed since, while the cabrei have been object of study in other parts of the Mediterranean in their quality of historical documents providing insights into land division and territorial administration (Caucci von Saucken et al., 1997; Ginori Lisci, 1978; Spiteri & Borg, 2015), no attempt had been previously done (to the best of our knowledge) to coherently integrate them in a GIS-based modelling strategy.

Study Aims

Our research sought to address a number of intertwined research questions, listed below:

1. Given the information stored in the *cabreo* maps, is it possible to identify environmental and cultural variables that can be considered determinants of agricultural quality in Malta?
2. What is the impact (if any) of the identified variables on the agricultural quality?
3. What overall patterns emerge when the predicted agricultural quality is extrapolated to the entire Maltese landscape?
4. Given that literature (e.g., Bevan & Conolly, 2013), ethnography, and common sense indicate that grazing journeys tend to avoid cultivated fields, is it possible to use the modelled agricultural quality as an heuristic tool to locate likely pastoral foraging routes across the Maltese landscape?
5. From a postdictive standpoint (Patacchini & Nicatore, 2016), how do the estimated foraging routes relate to other herd-related evidence present in the same landscape (i.e. features connected to movement of flocks between grazing areas, location of lost villages possibly linked to animal husbandry, or herd-related place-names)?
6. From the same standpoint, are the GIS-based postulated foraging routes consistent with the information provided by ethnographic accounts?

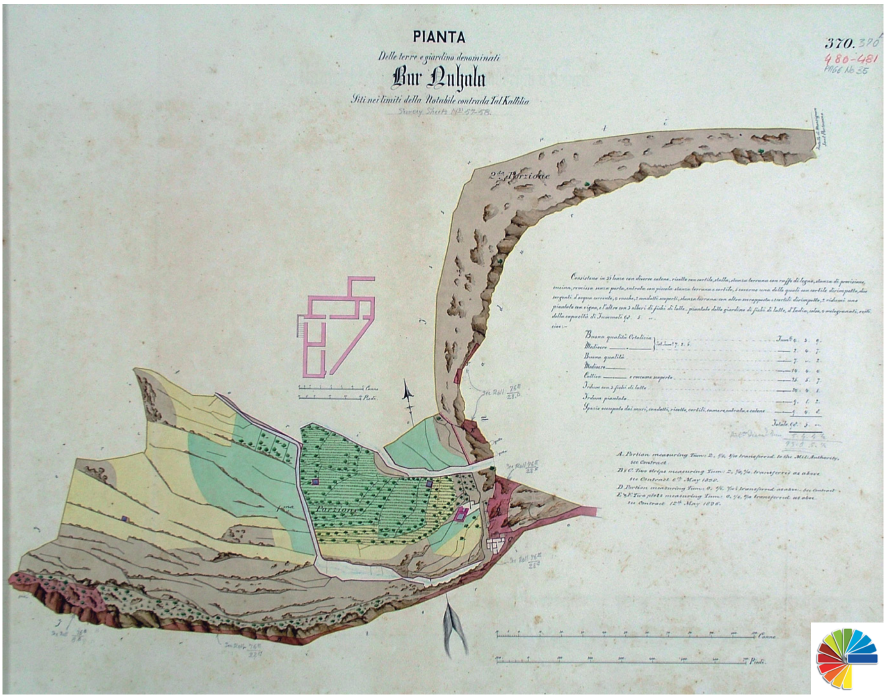
Materials and Methodology

Agricultural quality modelling

Questions (a) and (b) have been addressed using Logistic Regression (hereafter LR) (Hosmer, Lemeshow, & Sturdivant, 2000; Pampel, 2000) as a means to gauge the contribution of a set of topographic and cultural variables (hereafter predictors) on the chances for optimal agricultural quality. LR makes it possible to estimate the probability that a particular outcome of a binary dependent nominal variable will occur based on information from one or more predictors. For each predictor, LR allows estimating coefficients that, once exponentiated, can be meaningful interpreted as odds ratio (Pampel, 2000). An odds ratio of 1 leaves the odds for the positive outcome of the dependent variable (optimal agricultural quality, in our case) unchanged, while a coefficient greater or smaller than 1 increases or decreases the odds respectively.

In the *cabrei* (Figure 1), *agrimensori* (land surveyors) gave land parcels different colours according to a qualitative assessment of the agricultural yield (further details in Alberti et al., 2018). The full qualitative scale used in the cabreo was: *buona* (good), *mediocre* (mediocre), *cattiva* (bad), *inferiore* (lower), *infima* (lowest).

Figure 1. Example of cabreo map: the different colours are assigned to different sectors within the parcel to represent different agricultural qualities (e.g. brown=lowest quality, yellow=mediocre, green=good). Also note the hand-written notes systematically recording the number and type of structures present, presence and type of water facilities, presence of animal pens, and other information.



Courtesy of the National Archives in Malta; first published in Alberti et al., 2018

Out of several hundreds cabreo maps, a smaller more manageable sample has been georeferenced in GIS, and information about the location, extent, and agricultural quality of the parcels (or part thereof) was recorded with the use of 318 polygons. It was decided to collapse the *cabreo* classes into two broad ones, i.e. optimal (corresponding to the *good* class) vs. non-optimal quality (comprising the *mediocre*, *bad*, *low*, and *lowest* classes). Within the polygons, a total of 3,897 sampling points were drawn, and information about the dependent variable (agricultural quality, either as optimal or non-optimal) and about the value of a set of predictors at each sampling point, was extracted.

Different predictors have been used in the model: slope, elevation, aspect, planform and profile curvature, topographic wetness index, distance to geological fault-lines, to the coastline, to the 1895 road network (main, secondary, and minor roads), distance to footpaths, distance to 1895 urban areas, soil type, x (easting) and y (northing) coordinates. While modelling agricultural suitability is not a simple endeavour since a complex interplay of variables may indeed affect the inherent properties of the land (Akıncı et al., 2013; Prishchepov et al., 2013), the predictors used in this study were deemed useful based on the literature review and data availability. To avoid models with unnecessary complexities and to give preference to simpler models (Beh & Lombardo, 2014; Eve & Crema, 2014), we used a backward stepwise procedure (Austin & Tu, 2004; Rizopoulos, 2009), which is fully described elsewhere along with other more technical aspects of the modelling strategy (Alberti et al., 2018).

Addressing question (c) entailed using the coefficients estimated by the LR to predict the probability for optimal agricultural quality for those parts of the Maltese landscape for which no cabreo information was available. This, in turn, rested on using Map Algebra in GIS (Conolly & Lake, 2006) to implement the LR equation, which consists of values of the predictors plus the model's coefficient. In other words, once LR has been run, and the model's parameters (i.e., intercept and coefficients) have been found, it is possible to calculate the probability for optimal agricultural quality by plugging those parameters and any known value of the predictors into the logistic regression equation.

Pastoral foraging routes modelling

To address question (d), we have implemented in GIS the calculation of least-cost paths (hereafter LCPs), which is a widely applied approach in the study of how human behaviour relates and engages with movement across the landscape (Conolly & Lake, 2006; Herzog, 2014; Van Leusen, 2002; Wheatley & Gillings, 2002). We have conceptualized the cost of moving in terms of walking time since literature and ethnographic accounts (Arnon, Svoray, & Ungar, 2011; Endre Nyerges, 1980; E. Schlecht, Dickhoefer, Gumpertsberger, & Buerkert, 2009; Eva Schlecht, Hiernaux, Kadaouré, Hülsebusch, & Mahler, 2006) frame foraging excursions in terms of time spent to move from the starting location to the target grazing areas. Since livestock trails follow least-effort routes trying to minimise the impedance provided by the terrain's slope (Arnon et al., 2011; Ganskopp, Cruz, & Johnson, 2000; Stavi, Ungar, Lavee, & Sarah, 2008), we decided to implement the widely used Tobler's hiking function (Tobler, 1993), modified to fit animal walking speed. The latter is predicted as dependant on slope according to the following formula:

$$v= 6*exp[-3.5*abs(s+0.05)]$$

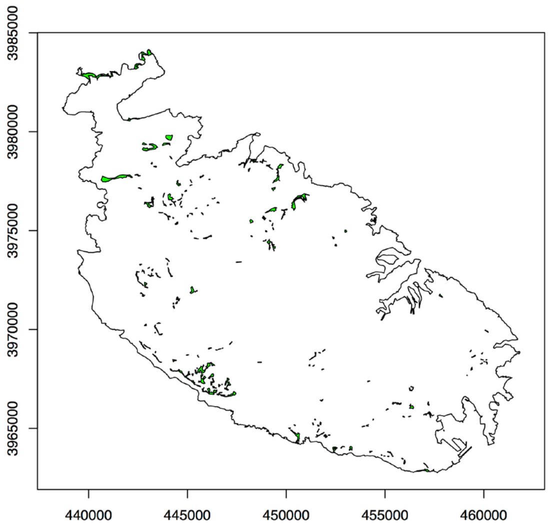
where *v* is the walking speed in km/h, *s* is the slope measured as rise over run. The maximum predicted walking speed of about 6 km/h is reached on a gentle (-2.86 degrees) downhill slope (Conolly & Lake, 2006, p. 218). In an attempt to find a balance between different animal walking speed values reported in literature (Arnon et al., 2011; Endre Nyerges, 1980; E. Schlecht et al., 2009; Eva Schlecht et al., 2006), Tobler's hiking function has been scaled down by a factor of 0.25 to represent the walking pace of a flock during excursions in which grazing takes place while walking, which in most situations can be considered a typical form of grazing (Arnon et al., 2011).

We calculated LCPs using ArcGIS 10.1's Path Distance tool (ESRI, 2017) following the procedure used by Tripcevich (2007). The calculation of LCPs employed garrigue areas, which we know were used for grazing (Lang, 1961; Rolé, 2007), as both the source and the destination of movement, in order to estimate the path network between them. Within the polygons representing the garrigue areas, a total of 139 random points were generated and used as destination points in the calculation of LCPs. In addition, two raster layers were fed into the Path Distance tool: a LiDAR-derived 10m DTM, and a slope raster used as the cost-surface. On the informed assumption that during their grazing journeys shepherds tend to avoid cultivated fields (Bevan & Conolly, 2013), the slope raster was preliminarily modified (e.g., Rogers et al., 2014, p. 264; White, 2015, p. 410) to factor agricultural quality into the LCP analysis. A higher slope value has been assigned to those parts of the landscape featuring a probability for optimal agricultural quality larger than 0.60, according to the cabreo agricultural model devised in response to the abovementioned research questions (a) and (b). This rendered those areas more costly to traverse.

Relation between estimated foraging routes and herd-related evidence

Research question (e) was addressed by coupling qualitative data with the use of quantitative approaches. The location and extent of landscape evidence linked to animal husbandry and herding belong to the former type of data. One of such pieces of evidence relates to those areas described as "public spaces" (waste land) by the colonial administration, which we imported into GIS from early 1900s survey sheets. A total of 217 polygons were employed (Figure 2).

Figure 2. Extent and location of areas described as "public spaces" (waste land) by the colonial administration; manually acquired into GIS from early 1900s survey sheets. In this and in the other figures, coordinates conform the UTM 33N ED1950 (projected) coordinate system.



These spaces, often overgrown and ideal for roadside grazing, may open up along the roads or tracks flanked by rubble walls, actually consisting in an enlargement of the area taken up by the road itself. While these spaces warrant further study, our working hypothesis was that public spaces acted as important nodes along the routes used for the movement of herds across the landscape. If that hypothesis held true, we expected public spaces to be spatially related to the estimated LCPs. To empirically assess this, we coupled descriptive statistics with a randomized distance-based approach (O'Sullivan & Unwin, 2010; M. S. Rosenberg & Anderson, 2011) implemented by one of us (GA) in an R package, which also contains other spatial analysis facilities and is freely available (Alberti, 2018). The distance of each public space's centroid to the nearest LCP was first computed. The 217 obtained distances were then averaged and the average was set against a distribution of average minimum distances calculated across 499 sets of random points drawn within a study window. The latter was the extent of Malta excluding the urbanized areas and those zones that the LCPs intentionally avoid (modelled probability of optimal agricultural quality larger than 0.60). The distribution of randomized average minimum distances is used to construct an expected distribution of public spaces-to-LCPs distances under the null hypothesis that public spaces are randomly located with respect to the latter. A p-value can be empirically worked out by calculating the proportion of cases in which randomized average minimum distances prove equal or smaller than the observed average minimum distance (Baddeley et al., 2016, pp. 384–387). The analysis of other evidence, such as the location of disappeared villages bearing the Maltese prefix *raħal* and the location of herd related place-names, is provided elsewhere (Alberti, Grima, & Vella, n.d.).

Estimated grazing journeys vis-à-vis ethnographic accounts

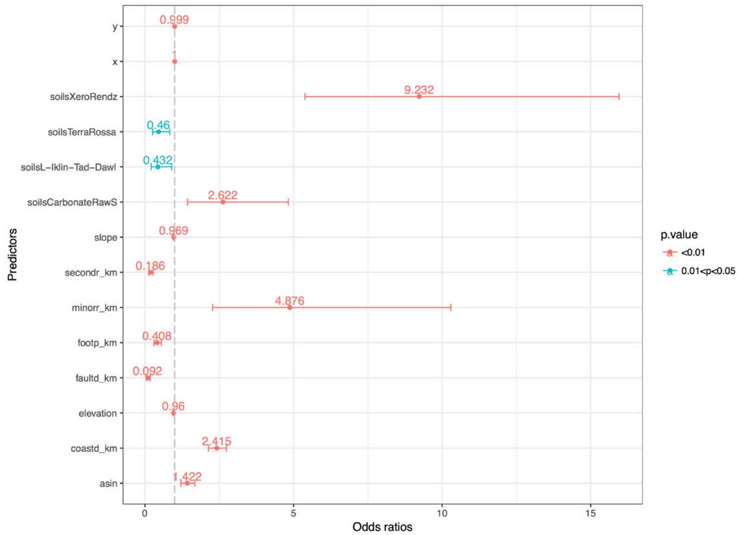
Research question (f) has been addressed by calculating the time it takes to move flocks from the farmhouses that were the object of the abovementioned ethnographic accounts toward those areas indicated by the informants as actual grazing land. These GIS-based estimates and the actual time details provided by the informants have been compared in order to gauge any existing match between them. A more extensive analysis, including the estimation of GIS-based foraging excursions starting from a number of farmhouses recorded in the mentioned sample of *cabreo* maps, is provided elsewhere (Alberti et al., n.d.).

Results

LR made it possible to locate a subset of predictors having an influence, either positive or negative, on the suitability for agriculture at the time when the cabreo was created. The selected predictors' odds ratio is reported in Figure 3.

Our findings indicate that terrain elevation and slope have a negative effect (odds ratio smaller than 1) on optimal agricultural quality. Literature indicates that elevation is associated with lower temperatures (Akıncı et al., 2013) and moisture content (Famiglietti, Rudnicki, & Rodell, 1998, p. 261). Furthermore, elevation may affect water retention since terrains at greater elevation may have more soil water draining down and are subject to receive less water from upslope (Qiu, Fu, Wang, & Chen, 2001, p. 737). Research elsewhere also indicates that steeper slopes tend to be drier than flat areas due to lower infiltration rates and higher surface runoff, and are also likely to have shallower soils (Qiu et al., 2001, p. 737; Tromp-van Meerveld & McDonnell, 2006, p. 300). Other things being equal, steep slopes also feature a higher amount of solar energy (Chang, 2009; N. J. Rosenberg, Blad, & Verma, 1983), since the quantity of solar radiation per unit area of the land surface decreases as the slope decreases. Steeper slopes are also more difficult to cultivate relative to more gentle sloping terrains (Akıncı et al., 2013, p. 75; Stewart, 2013, p. 27).

Figure 3. Logistic Regression results: predictors' odds ratios (point estimate plus 95% confidence interval) representing the influence on the chances for optimal agricultural quality. A value smaller or larger than 1 decreases or increases the chances by a factor equal to the odds ratio respectively. Colour code: light blue=p value between 0.01 and 0.05; red=p value smaller than 0.01.



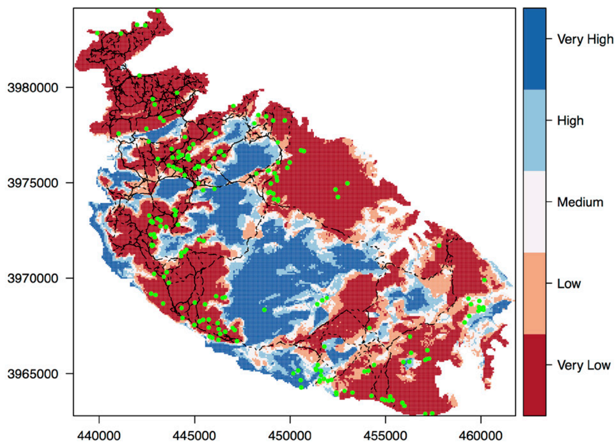
In our model, easterness (i.e. sine of the aspect, abbreviated as *asin* in Figure 3) and distance to the coastline have a positive effect on the optimal agricultural quality, while the distance to the nearest geological fault has a negative influence. Literature shows that slope orientation affects solar radiation and evapotranspiration, soil moisture, and soil nutrients (Begum, Bajracharya, Sharma, & Sitaula, 2010; Famiglietti et al., 1998; Qiu et al., 2001, p. 736; Reid, 1973). Furthermore, slopes with different orientation are differentially subject to prevailing winds. The positive influence of eastern aspects on the optimal agricultural quality can be explained by the fact that east-facing slopes are relatively cooler than southern and western exposure, so retaining more soil moisture and featuring a lower rate of evapo-transpiration (Anderson, 1997, p. 111). It is also worth noting that west-facing and southwest-facing slopes receive a greater amount of solar radiance, resulting in drier conditions and in a different microclimate at ground level (Sulebak, Tallaksen, & Erichsen, 2000, p. 91). The positive impact of the distance to the coastline can be explained by the fact that being further away from the coast implies being less prone to sea-spray and salt-laden air. On the other hand, since the distance from the nearest geological fault is a proxy for fresh water availability (Alberti et al., 2018), the model indicates that being far from a fault line translates into a decrease in the chances of having access to fresh water, which is a crucial factor in the development of agriculture in arid climates (Vella, 2001).

Our model also allowed us to gauge the influence of different soil types on the agricultural quality. Brown Rendzinas soils have a positive effect, and the same holds true for Carbonate Raw and Xerorendzinas soils, while Terra Rossa soils are associated with a negative effect. Our findings confirm many of the empirical observations made in the 1960s by Lang, who noted that Xerorendzinas, Brown Rendzinas, and Carbonate Raw soils used to give satisfactory crops, while Terra Rossa soils were left uncultivated since they were rather dry, compact, and difficult to cultivate (Lang, 1961, p. 94).

As for land accessibility, the distance to the nearest secondary road and to the nearest footpath was found to have a negative effect on the optimal agricultural quality. This makes sense since the secondary road network can be thought of as allowing a gradual shift from urbanized areas to more peripheral zones, going deeper into the landscape relative to the main road system (which, remarkably, turned out not to have a significant contribution to the model), and providing access to the countryside. The same holds true for the distance to the nearest footpath, which has a negative effect. On the other hand, the distance to the nearest minor road is associated with a positive influence on agricultural quality. While its interpretation is less straightforward (Alberti et al., 2018, p. 21), the result of the model would indicate that, since minor roads occur in areas of garrigue and karstland which are generally less favourable for agriculture, optimal land quality would be found further away from minor roads, downslope or in valley bottoms.

Besides gauging the effect of the isolated predictors on the agricultural suitability, our analysis allowed the extrapolation of the predicted agricultural quality to the entire Maltese landscape. The estimated regression coefficients have been plugged into the ArcGIS raster calculator to perform a map algebra operation that produces the image in Figure 4. It represents the fitted model and features a colour scale reflecting the probability for optimal agricultural quality. It is apparent (as will be discussed later on) that there is a considerable variability of agricultural potential even over small distances, with large zones highly suitable for agriculture, and other ones (e.g., the karstic plateaux) featuring the lowest suitability value.

Figure 4. Fitted agricultural quality model for the entire Maltese landscape: the colour scale indicates the probability for optimal agricultural quality according to the cabreo model and is broken down into five classes (very low corresponds to a probability of optimal agricultural quality between 0.0 and 0.2; low: 0.2-0.4; medium: 0.4-0.6; high: 0.6-0.8; very high: 0.8-1.0). The estimated least-cost paths (black lines), representing potential pastoral foraging routes, and the location of public spaces (green dots; see also Figure 2) are also shown.

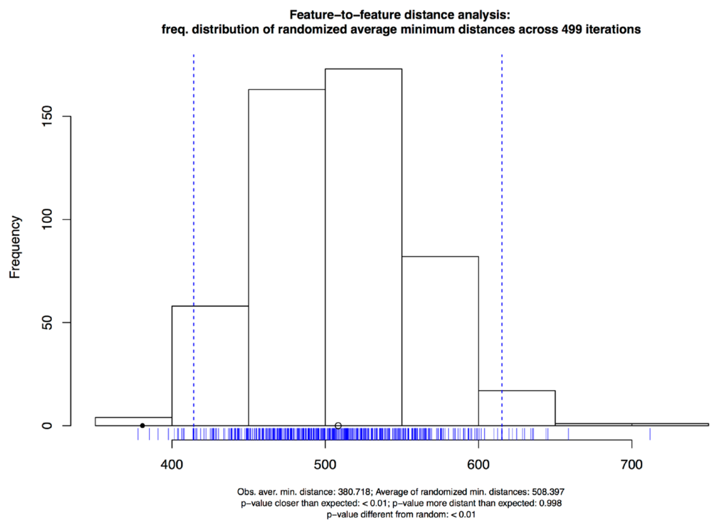


The *cabreo* model has been used as a constraint for the calculation of LCPs representing pastoral foraging routes between garrigue areas used as pastures. The abovementioned Figure 4 shows the potential routes along which a foraging journey may take place. The calculated paths (139 in total) minimise the traversed slope, as expected: the minimum and maximum average slope is 1.28 and 15.77 degrees respectively, the median average value is 5.19, with 90 per cent of the cases having an average slope equal to or smaller than 9.76, and just the top 10 per cent of the cases featuring an average slope between 9.76 and 15.78. As already noted, the LCPs tend to avoid areas with a high probability for optimal agricultural quality, valley bottoms in particular. The median average probability of the terrain they traverse is 0.05, with a minimum and maximum equal to 0 and 0.51 respectively. In 90% of the cases it is equal to or smaller than 0.23.

From a postdictive standpoint, we gauged the plausibility of the estimated LCPs by assessing their spatial relation with above-mentioned public spaces. We found that public spaces tend to lie close to the estimated LCPs. Their median planar distance to the nearest LCP turned out to be 89 m. Cumulatively, 73% (159) lie within a distance of 300 m, and only

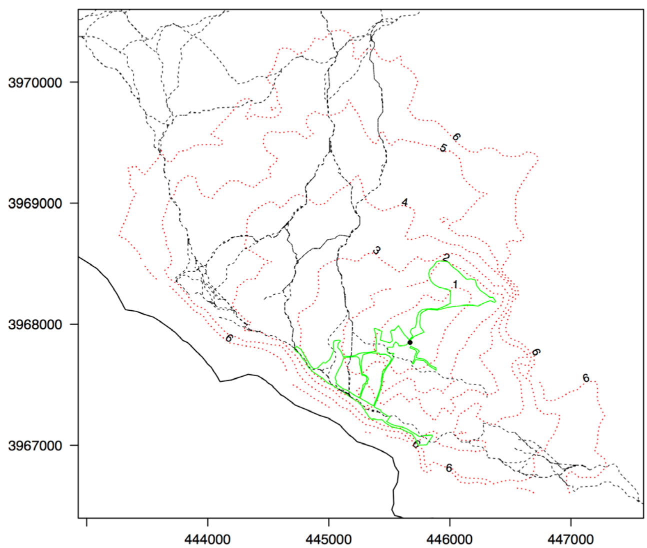
12% (27) feature a distance equal to or larger than 1 km to the nearest LCP. Remarkably, these more distant public spaces (see Figure 4) are mainly located at the fringe of the densest urbanized area of the island, which would indicate that they could possibly have been related to garrigue areas cancelled out by modern urbanization. Our analysis also showed that the observed average minimum distance between public spaces and LCPs is 380 m, which is smaller than the average of the randomized minimum distances, which is equal to 516 m. The tendency for public spaces to lie close to the estimated LCPs proved statistically significant, with a p-value equal to 0.004 (Figure 5).

Figure 5. Test for spatial association between public spaces and estimated pastoral foraging routes (see also Figure 4): the histogram shows the frequency distribution of randomized average minimum distances, calculated across 499 iterations. The observed average minimum distance between public spaces and foraging routes is 380 m (solid black dot), while the average of the randomized minimum distances is 508 (hollow dot). The blue lines at the base of the chart represent the 499 random average minimum distances. The observed average minimum distance falls in the left tail of the distribution, with an associated p-value of 0.004. Test performed in R using the 'GmAMisc' package (Alberti, 2018).



Our GIS-based estimates also proved consistent with ethnographic data to which reference has been made earlier and which is object of a larger analysis provided elsewhere (Alberti et al., n.d.). These data relate to practices dating between the 1950s and 1970s when the informants used to tend flocks with their father or other relatives. A shepherd living in the Għar il-Kbir area reported that the main grazing area for his flock consisted of the garrigue zones lying immediately southwest and northwest of his farmhouse, along the escarpment of the Dingli Cliffs and at Il-Bosk respectively. His foraging excursions used to be done between 6:00 and 8:30 a.m. in summer (June-October), and between 9:00 and 14:00 in winter (November-May). The duration of the reported excursions are consistent with the accumulated (animal) walking time surface calculated moving from the farmhouse outwards (Figure 6).

Figure 6. Isochrones (red dashed lines) around the farmhouse (black dot) located in the Għar il-Kbir area (west-central Malta): isochrones enclose the space that can be covered on foot during the time intervals (hours) indicated by the numbers. The walking time is estimated on the basis of the slope-dependant Tobler's hiking function, adapted for animal walking speed while grazing. The green lines represent the extent of the area used by the farmhouse owner as grazing ground for his flock. Black dashed lines represent part of the garrigue-to-garrigue least-cost path network corresponding to estimated pastoral foraging routes (see also Figure 4).



The grazing area immediately surrounding the farmhouse lies well within the 1-hour walking time buffer. The larger garrigue zones southwest of the farmhouse, lying between the Maddalena Chapel and Ta' Żuta, is reachable within four hours, while the foraging area lying to the northeast at Il-Bosk can be reached within a maximum walk of two hours. In these settings, it is possible to complete the two legs of the journey (outbound and inbound) well within the limits of the time windows reported by the informant, especially during the most time-constrained summer excursions.

Discussion

Our research into the development of the Maltese landscape proved both challenging from a methodological standpoint and intriguing in its findings. The research provided the unique opportunity to set qualitative and quantitative data in a common analytical framework and to work out methods to make the most out of both. For the first time in the literature (to the best of our knowledge) our research has made use of mid-1800s cadastral data not as simple cartographic base-maps, but as building blocks for agricultural suitability modelling. It has been possible to isolate a number of environmental and cultural predictors that are likely to have affected agricultural suitability before heavy mechanization. The different contribution of the different predictors has been gauged for Malta for the first time.

The cabreo model we have devised has also allowed us to generalise from our sample of maps to the entire landscape, enabling to arrive at a broader inference regarding the whole landscape. This has brought to the fore one of the striking characteristics of Malta, which is the wide variability in land quality even over small distances. As apparent from the mentioned Figure 4, the modelled landscape in Malta turns out to be a complex patchwork featuring different agricultural potentials and resulting in dramatically different micro-environments. The fragmented and variable nature of the Maltese landscape is evidently an enduring characteristic, which would have been no less variable in more remote periods. Mixed subsistence strategies, such as those combining animal grazing and food collecting on more inhospitable areas with crop cultivation in more sheltered and favourable zones, appear to be better suited to such an environment.

Our coupling of a predictive approach (cabreo model) with a postdictive analysis (GIS-based pastoral foraging routes estimation and comparison with other evidence on the ground and with ethnographic data) has allowed to add more dimensions to the analysis of the use of the Maltese landscape, and to further characterise that part of the landscape that has been flagged by our model as not optimal for agriculture. The LCPs estimation allowed us to locate potential pastoral foraging routes connecting "less productive" areas.

This apparently unproductive landscape was indeed an important part of the agrarian economy. In fact, the uncultivated areas provided grazing grounds for sheep and goats as well as quarried stone for construction, brushwood for fuel, apart from herbs, greens, wild game, and flowering plants for bee pasture (Blouet, 1963; Forbes, 1996; Lang, 1961; Rolé, 2007; Wettinger, 1982).

The use of quantitative approaches enabled the assessment of the plausibility of the estimated pastoral foraging routes vis-à-vis other independent herd-related evidence, such as the location of public spaces. While our findings cannot be used to claim a causal relationship between the estimated LCPs and public spaces, the tendency of the latter to lie close to the former is taken here to indicate a functional connection between the two. The importance of public spaces for economic activities as important as agriculture, such as animal husbandry, is witnessed by the investment in demarcating such apparently unproductive areas with rubble walls that permitted access to them for humans and herds through walled paths or tracks, while segregating them from sown land. They represent the embodiment of those strategies aimed at optimising the exploitation of land that was less optimal for agriculture.

Our research has also sought to couple, again for the first time, GIS-based analyses and ethnographic accounts. From a postdictive perspective, it turned out that the timing of estimated foraging excursions is broadly consistent with the information provided by our informants. All in all, our findings on the modelled agricultural quality, our GIS-based estimation of pastoral foraging routes, their relation with public spaces, and the comparison between modelled data and ethnographic accounts regarding foraging excursions, provide us with a portrait of intensive exploitation of the landscape. This was achieved through a mixture of strategies, each adapted to the highly variable affordances presented by those different micro-environments to which reference has been made earlier. The relationship between these different strategies, most notably between crop cultivation and pastoralism, was very carefully managed and regulated.

Conclusions

This chapter has sought to describe the main achievements of our research into several aspects of the Maltese landscape in recent historical periods, while highlighting the ways in which different analytical approaches may be combined and applied to better understand social and cultural phenomena. From this standpoint, our research is considered to break new ground for a number of reasons. First, the joint analysis and reconstruction of the ways in which the landscape has been exploited for different economic tasks represents a novelty in the literature regarding Malta and the Mediterranean area more generally.

Secondly, the historical development of the Maltese landscape has been approached from a GIS perspective for the first time. Thirdly, qualitative data such as cadastral maps and ethnographic accounts have been set within a modelling framework that makes explicit use of cutting-edge geo-spatial methods. Overall, the research has sought to approach the development of the Maltese landscape from a novel perspective, in which different types of data, once set in a robust, coherent, and explicit methodological framework, have converged to shed a new light on the layered development of the landscape in Malta.

Acknowledgments

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CHAPTER 2

The use of an Enterprise Database

Brian Borg and Omar Hili

Introduction

The use of an ESRI enterprise Geodatabase

Enterprise geodatabases mainly cater to large demands in Geographic Information (GI) Data consumption. Esri© software is also flexible to run on Linux or windows and within your local infrastructure and publish to the general and specific public. This document will demonstrate how an enterprise Geodatabase can be used to develop specific integrated and custom systems for large authorities.

Design of an Enterprise GI Publishing service using a GeoDatabase

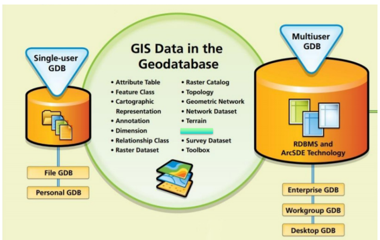
A main feature of Databases is the concurrent use of their data through different sources. GeoSpatial web services have become day-to-day use in geoportal and data dissemination. Nowadays geospatial software allows data in an enterprise geodatabase to be published worldwide, using OGC standards (OGC, n.d.) to freely disseminate data to the public.

A single-user database allows the creation of a local database to be consumed and edited by one user at a time and can be saved in a local network directory without the use of any Sequel, Oracle or other Database servers. Various free and proprietary geospatial software handle connections to the Single user GDB database. A single user Database is mainly used for testing and creation of new data and also as a small repository of temporary projects and is intended for an individual GIS user. A multi-user database needs to have a database server installed. An example of proprietary software that allows such executions is an ESRI Enterprise database which is mainly an addon on top the of SQL server to provide the functionality to query and create spatial data on the Geodatabase. (Esri, 2009). Open-source databases such PostGIS SQL offer spatial databases but lack the ability to publish results through a service thus the option to use ArcGIS software.

Figure 2 displays the typical configuration of a multi-user Enterprise Geodatabase. The data storage is a standard RDMS and ArcSDE and Arc objects are installed on top. The spatial component is what makes the Enterprise Geo-database unique and allows for attributes like Raster datasets, Geometry services, vector data, and other various geodetic features.

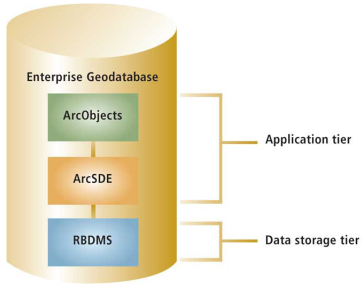
The enterprise geodatabase also allows externally developed software to be integrated with the ArcSDE database and thus develop applications to read and write data to a spatial database and most important be able to perform spatial queries.

Figure 1: Types of Databases, single-user and multi-user including attributes



Source: esri.com/geodatabases, 2009

Figure 2: Enterprise Geodatabase configuration



Source: Esri, 2009

Since Esri`s Geodatabases use a standard connectivity platform, and as previously stated, offer dissemination services, developers have the ability to create custom software which uses web services to externally communicate with the spatial data within the geodatabase. An Esri Geodatabase cannot be directly accessed via the Sequel server or an Oracle console but only via the services which ESRI offers. Arcserver has a unique way of storing delta tables for geometry files and such data can only be manipulated via Esri Api and software (Esri, 2019). The next section will provide information on various Governmental entities that have used ESRI enterprise Geodatabase to build custom software for their day-to-day use.

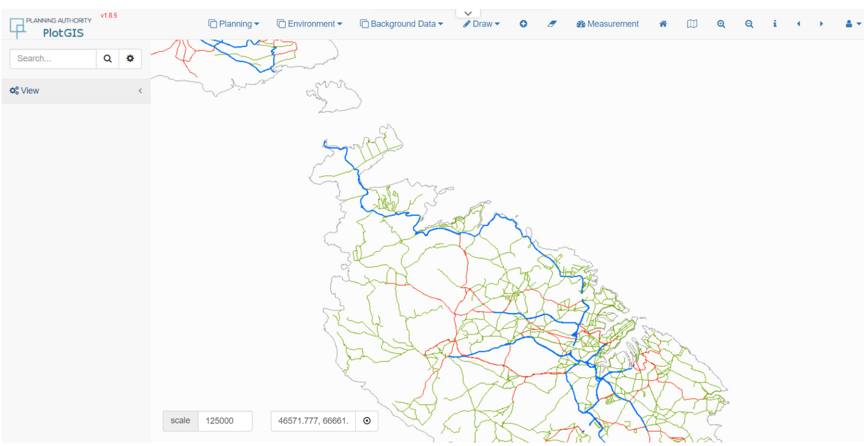
Results

Custom third-party application using ESRI Geodatabase for the day to day running of Governmental systems: PlotGIS

The Malta Planning authority has developed a Web application for its application plotting system. Each application received is plotted onto its geographic location and forms part of the initial stage of the application. Such information is disseminated to the public via the authorities' Geoportal.

PlotGIS is a web application that integrates itself with the Web services published Via ESRI Geoserver. The web services act as an interface between the Geodatabase and the Web applications. The systems use Active directory login credentials to identify the user and such user has the rights to edit the enterprise Geodatabase via the Web applications using ESRI libraries, API and Java scripts In his master dissertation Sozen (2017) emphasises on architectures and particularly on web applications using such Api and Java scripts. Figure 3 displays the front-end interface for the online plotting system. A very strong feature ESRI`s enterprise Geodatabase has is the ability to allow multiple connections to read from the same feature thus enabling the immediate display of data on the Authority Geoserver. The Geoserver is used by internal employees to review a plotted area and be able to assess and constraints that the plot falls within. Since the Geoserver can read simultaneously from the database, once Plotgis writes a new parcel the Geoserver immediately displays such parcel, thus having a more responsive and efficient system. This is a live system that constantly communicates with the geodatabase to create, delete or edit parcels and such changes are instantly reflected for end end-user since the same database acts as the provider of information of the live service. In this case, a live database is created which serves as a data store and data provider.

Figure 3: The Planning Authority PlotGIS interface



Source: Planning Authority, 2018

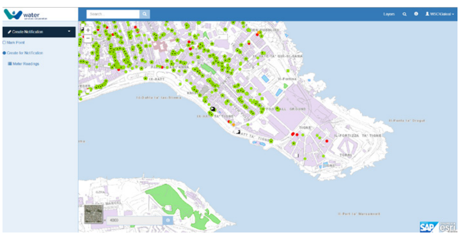
GIS Integration

Given that GIS integration was strategically one of the major corporate targets, the Corporation embarked on the development of software packages specifically designed to provide all the GIS functionality and at the same time integrate all systems wherever required. Of special mention was the development of GIS Centric solution into specifically engineered to integrate GIS to the corporation's main ERP system (Patel, 2013), specifically but not solely with main steams namely enterprise asset management (EAM) and Supply Chain Management (SCM).

AquaDot CRM, AMM and SCADA

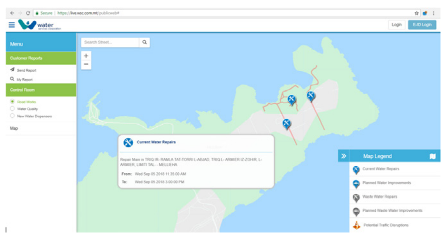
Three of the major areas which have in the past years seen major GIS/SAP integration developments were Customer Relation Management (CRM), Automated Meter Management (AMM) and SCADA. This AquaDot CRM integrated solution has been entirely developed within the corporation's strategic information directorate. A winning edge element in this solution is the GIS-ERP integration with the main aim to promote Customer relation, Guerola et. al (2022) describes such systems as opportunities to satisfy customers' new and changing needs. This essentially means that the solution is enabling customer care agents to geo-code customer notifications through a GIS interface and seamlessly update and maintain the ERP EAM. Consequently, the solution apart from improving the efficiency required to address customer complaints, is also capturing valuable geographic data which is eventually transformed into information and spatial knowledge. This provides information and knowledge which are extremely valuable and useful for decision-making.

Figure 4: AquaDot Customer Care system



Source: AquaDot, 2018

Figure 5: WSC GIS Based Public Live portal



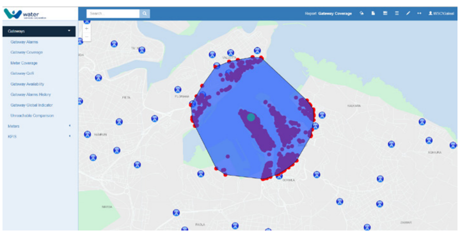
Source: WSC GIS, 2018

The WSC has also developed a public GIS-centred portal whereby water network-related works, which might possibly lead to traffic disruptions, are effectively indicated on a map and at street level.

AquaDot AMM

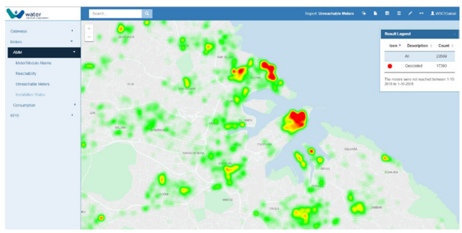
AquaDot AMM is another in-house-built solution revolving around the operational management of automated metering. Baird (2011) describes such system as as the expressways of our future for utilities to transform data into informative information which is necessary to make informed decisions in day to day operations. GIS is also central to this solution and through SAP integration, is perhaps amongst the first applications to be developed through a GIS-centric perspective. AquaDot AMM is today providing our technical people with all the required information and knowledge to efficiently manage all AMM operations. It helps to identify the location of faulty meter transmitters and the optimization of Radio Frequnecy receiver reachability. Another very useful feature is that of identifying and eventually notifying consumers of a possible water leak within their household. All this is possible by reaping the powerful benefits of GIS and SAP integration (Sassi, 2020).

Figure 6: AquaDot AMM screen featuring radio communications monitoring



Source: AquaDot, 2018

Figure 7: AquaDot AMM featuring location intelligent visuals

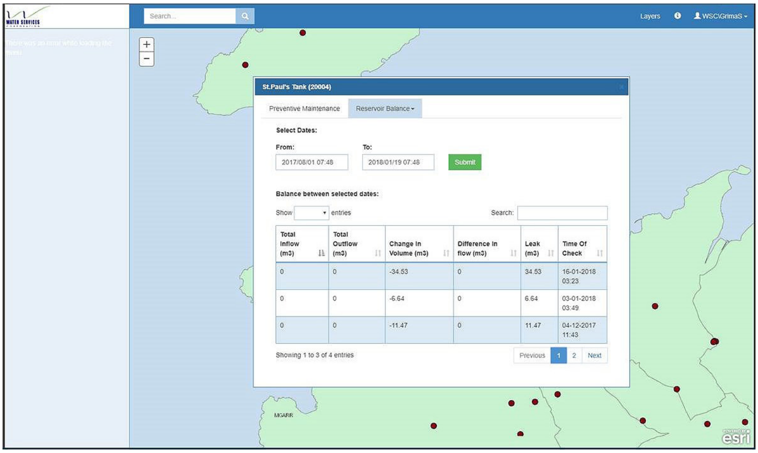


Source: AquaDOT, 2018

Supervisory Control and Data Acquisition (SCADA)

Since 2002, the WSC has maintained a SCADA system which is implemented across both water and wastewater networks. Through these years, the SCADA team gained extensive expertise in this area and can easily provide expert consultancy in this specialised field (Aburaew, 2011). AquaDot SCADA was another solution developed internally to cater for the monitoring of designated networks and equipment (Elgy, 1996). This system provides controllers with an extra edge to deploy the required resources in terms of efficiency.

Figure 8: AquaDot SCADA monitoring solution



Source: AquaDOT SCADA 2018

Conclusion

After years of GIS implementations, we can confidently affirm that the methodology approach adopted proved to be extremely beneficial. In the past years, we have seen leaps in effective decision-making and the success of cost-effective plans. GIS is also providing WSC with the perfect communicative tool, especially with respect to visually conveying water network-related site plans and other location-intelligent imagery. Having gained first-hand knowledge and experience of what can be attained through GIS, the WSC is now committed to keep abreast with new emerging technologies, striving to get the most out of innovative technologies.

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CHAPTER 3

Modelling spatial urban redevelopment in Malta using agent-based models

Frank Farrugia

Introduction

Modern urban areas require careful management, planning, and investment (Rydin, 2011). The policymaker has the delicate and challenging role of trying to strike a balance between three important factors: urban development, natural environment and the sustainability of urban areas (Musakwa & Niekerk, 2013; Shao, 2015). However, this balance is not always clear-cut (Birkin, 1996). GIS in urban planning holds the potential to provide higher-quality quantitative and qualitative data analysis, enhancing both the decision-making process' knowledge base and its evidence foundation (Maarseveen et al., 2019). GIS is able to take into consideration different factors, explore data, apply queries and analysis as well as, be capable of visually presenting results as understandable presentations (Batty, 1992; Dekolo & Oduwaye, 2005). Often the results can flag issues that otherwise could have passed unnoticed (Longley et al., 2015). Carrying out spatial analysis in urban studies, planners can evaluate the impacts and relationships on the urban morphology, as well as identify the drivers that affect these relationships (Lai & Han, 2012; Zeng et al., 2008).

Transportation and land use patterns, attributes to urban morphology affecting social interactions differently across areas, as well as how this might affect social segregation and equity. (Farber et al., 2013). Therefore, GIS can play an important role in the urban planning process by providing support to the urban planner to make an educated decision when, for example, preparing policies or development zoning maps. Pursuing sustainable development requires effectively modelling impacts of urban developments. Researchers have utilised various models to understand urban growth, conventionally, Agent-Based Models (ABM) and Cellular Automata (CA) (Cheng, 2003; Lai & Han, 2012). The behaviour of agents on land change is best achieved through ABM (Jokar Arsanjani et al., 2013; Kim, 2012) since agent-based modelling is more suited to mimic situations and behaviours in a realistic way (A. Crooks, 2012). The integration of GIS and ABMs are based on simple rules which may result in the emergence of complex system behaviours (Batty, 2012).

Theorical Issues

Spatial proximity analysis has been used in various studies varying from environmental risk to determine the influence of neighbouring catchments in regional flood to studying on urban planning purposes, for example, the impact of lake proximity to residential real estate prices (Beames et al., 2018). Table 1, adapted from Lee and Chan (2008) and Wang et al., (2015) lists various factors that are in play in the process of land redevelopment.

Table 1. Urban design considerations attracting Urban Redevelopment

Proximity to
• Coastline and coastal areas • Commercial Areas • Industrial areas and enterprise Hubs • Key Areas for Recreation (open spaces) • Government projects • Service utilities such as transport hubs, medical centres, educational facilities, places of worship, airports. • Sports Areas • Tourism areas • Road network

Note: adopted from Lee and Chan, 2008; Wang et al., 2015

To cater for growth in population and changes in economic and social needs, urban areas are redeveloped by demolishing houses, offices and shops, and replacing these with new premises and providing various types of amenities (Ghesmi Shah Galdi et al., 2017). Lee and Chan, (2008), Mahamud et al. (2016) and Ghesmi Shah Galdi et al., (2017) have all shown that access to open spaces, transportation arrangement and community contribution are important factors in urban redevelopment. Zhou et al., (2017), argue that social and community facilities, open space and business attribute to higher property prices. Each of factor has a weighting indicating its importance on other factors (Mahamud et al., 2016; Malczewski & Rinner, 2015). A weight is a value given to an evaluation criterion and indicates the importance of that criterion relative to another criterion under consideration. This criterion weighting can be identified using the Analytic Hierarchy Process (AHP) (Malczewski & Rinner, 2015). Analytic Hierarchy Process (AHP) is one method of MCDM that can be implemented within GIS to define weights of criteria (Rad & Haghyghy, 2014) and is suitable at establishing different weights across many indicators

(Schuurman & Bell, 2014). AHP introduced by Saaty (1980), reduces complex decisions to a series of pairwise, compares matrices and then issues results.

AHP and GIS have been used as a tool in urban planning in determining a weighting associated with drivers of urban growth (Abdullahi et al., 2015; Birkin & Wu, 2012; Mahamud et al., 2016; Masel Ullah, 2014; Parry et al., 2018). Each identified factor is compared at a time in terms of their relative importance to each other and calibrated on a numerical scale from 1 to 9 (Table 2). If factor A is equally important as B, the pair receives a 1, while if factor A is more important than B, factor A receives a 9 and factor B receives 1/9 since B is less important than A. How important a factor is on another is derived by taking into consideration the percentage and sample size of each factor. The importance of the factor or judgement produces a matrix. The sum of each of the matrix rows is divided by the number of elements in the row. This process normalises each column of the matrix to sum to 1.0 or 100%. As a check, the true consistency ratio is calculated. A consistency ratio of 0 shows that the judgment is perfectly consistent (Xi and Qin, 2013).

Table 2. AHP fundamental scale

Intensity of importance	Definition/explanation
1	The criteria are equally important; alternatives are equally preferred/equally contributing to the objective.
3	Experience and judgment slightly favour one activity over another. The criterion is moderately/slightly more important than the comparable criterion.
5	Experience and judgment strongly favour one activity over another. The criterion is strongly more important than the comparable criterion; the alternative is strongly more preferred.
7	Very strong or demonstrated importance. The criterion is powerfully more important than the comparable criteria.
9	The criterion is extremely more important than the comparable criterion; the alternative is extremely more preferred, highest possible favouring of one criterion over another.
2, 4, 6, 8	Intermediate values when compromise is needed.

Note: adapted from Saaty, 1980

Agent-Based Modelling (ABM) and GIS

Cheng (2003) lists different various modelling techniques that can be used for analysing urban systems. Amongst the most popular methodologies to model and study urban areas are computational models such as Cellular Automata (CA) and Agent-Based Modelling (ABM) (Torrens, 2003). Agent-Based Models have been found to be more effective in supporting planning and decision making in urban studies (Lai & Han, 2012). The state of an agent in a CA can change but maintains a fixed position. On the other hand, an agent in an ABM change both state and position, has full control of its behaviour, and can interact freely with each other and their environment across space and time (Batty, 2012; Dijkstra et al., 2011; Railsback & Grimm, 2012). Agents in models are objects that represent individuals or entities such as urban development (Crooks et al., 2018). Urban areas emerged from a bottom-up (Batty & Xie, 1994; Nijkamp & Reggiani, 1992). Likewise, ABM models adopt a bottom-up approach to understand cities such as urban renewal, redevelopment, sprawl and segregation over time (Castle & Crooks, 2006; Clarke, 2014; Rui & Ban, 2010).

A bottom-up approach sets the behaviour and characteristics of an agent at an individual level as opposed to a top-down approach which specifies global characteristics and behaviour (Crooks et al., 2018; Teweldemedhin et al., 2004). ABM has been used to understand the complexities in human behaviour and one example of this is Thomas Schelling's model of segregation (Schelling, 1969). Heppenstall et al., (2016) argues that cities develop on a myriad of individual decisions, whereas, ABMs operate on a set of mathematical rules. Heppenstall et al., (2016), also contends that there are three influences which determine the role that ABMs will play in the creating city models. These are spatial scale, temporal scale, and agent behaviour.

Following its completion, the ABM needs to be evaluated, which involves three main steps: verification, calibration, and validation (Railsback & Grimm, 2012). There are no specific techniques for the verification of agent-based models, however, the most used method, is testing and verifying the code by testing this against logical errors - to confirm whether the logic of the model is acceptable or not (Crooks, Malleson, et al., 2018; Gürcan et al., 2013). No simulation model can perfectly replicate the real situation. Thus, the model needs to be calibrated and validated against fit data to closely replicate the real world (A. Crooks, Malleson, et al., 2018). Crooks et al. (2018), argues that fitting the data depends on the type of data being compared, the scale of the analysis and the desired outcome. Crooks et al. (2018) split methods to determine how well the model fits i.e. calibration and validation, into four categories: visual comparison, global statistics, description of point data, and local indications of spatial association.

For vector point data, the most appropriate spatial statistical testing is point maps and Kernel Density maps for visualisation and Dual KDE for local indications of spatial association (Crooks, Heppenstall, et al., 2018). To assess distribution, QQ plots are also a good graphical tool to visually compare two datasets, such as data distribution between the simulated and observed dataset match (Fachada et al., 2015; Loy et al., 2016). Validation is associated with calibration. While calibration fine-tunes the model, validation tests its performance and measures how the simulated data matches the real world (Heppenstall et al., 2016; Wikstrom et al., 2019). During validation, no calibration is carried out and is compared with equivalent real data. The same method used during calibration, is used in the validation stage (Crooks, Malleson, et al., 2018). Van Vliet, (2013) suggests that when sufficient data is available, the model is independently validated, which means that the data used for validation is not the same data used for calibration.

ABM Toolkits

There are various simulation platforms, Netlogo (Tisue & Wilensky, 2004), Repast (North et al., 2006) and GAMA (Taillandier et al., 2019) to name a few. GAMA has the extended ability to georeference each agent on a vector point representation in GIS and does not have a limit on the number of agents, allows the reading and writing of GIS data and allows the addition of as many environments as required in the model (Crooks, Malleson, et al., 2018; Grignard et al., 2013; Taillandier et al., 2012, 2019). GAMA was designed with advanced management of spatial vector data, also allowing the geometry of agents either directly defined by the modeller or loaded from geographical data GAMA uses GAML language which is coded in Java (https://GAMA-platform.github.io/) which allows many advanced spatial operations such as spatial queries, union and intersection (Grignard et al., 2013).

ODD Protocol

Grimm et al. (2006) proposed a standard protocol – ODD – which stands for "Overview, Design Concepts and Details", to describe agent-based simulations. By following the descriptions of a set of properties for a model, it allows an easier way to both write and read model formulations (Railsback & Grimm, 2012). The ODD protocol has a simple structure using natural language to describe the ABM model. Through its prescriptive and hierarchical structure, the ODD protocol aids the model design and promotes in-depth model comprehension (Fachada et al., 2015). The ODD protocol is compromises three categories: Overview, Design and Detail.

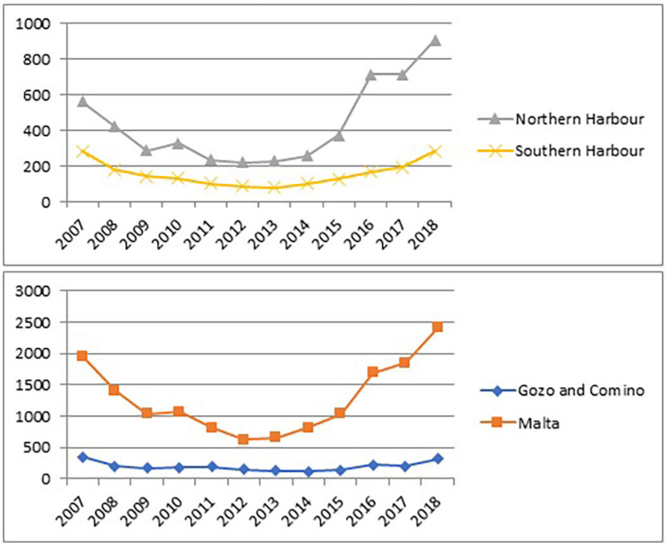
Methodology

As stated above, this study was developed in two parts. In the first part, ArcMap 10.6.1 with the Spatial Analyst extension was used to carry out a proximity analysis to determine which zoning typology has the most influence on urban redevelopment. The proximity analysis was carried out on redeveloped sites between 2007 and 2018 (with a planning permission) against how far these sites were from the zoning typologies. The closer the redeveloped site was to the zoning typology the more influence that zoning typology had on redevelopment. Following the analysis of the proximity investigation, those zoning typologies that had the most affect redevelopment were identified. An AHP method was then used to determine the weights of these identified factors, which were subsequently fed in the ABM to influence the agents' behaviours and decision. Adjusting parameter weights have an impact on the agents' choices (Tian & Qiao, 2014). The second part involved the development and implementation of the ABM. The literature review provided a basis to develop the ABM conceptual model to describe the agents and their relationship amongst the agents as well as the environment. The agents represent redevelopment and exist on a two-dimensional landscape. The environment represents three LAUs in Malta in vector format. The conceptual model is described using the ODD protocol. After finalising the conceptual model, the model was translated into a coding script using GAMA platform, which was calibrated and validated.

Variables for Analysis

As stated above, this study, is based on three districts, Gozo, and Comino and two LAUs in Malta, namely Northern Harbour and Southern Harbour. Although the Northern Harbour and Southern Harbour are adjoining LAUs, the Northern harbour LAU saw the largest number of approved requests for redevelopment, while Southern Harbour LAU had the smallest approved request. Moreover, the Southern Harbour redeveloped at a slower rate than the Northern Harbour. Gozo is the second-largest island in the Maltese Islands. Unlike Malta, redevelopment in Gozo between 2007 and 2018 occurred in a linear fashion (Figure 1).

Figure 1: Comparing approved requests for redevelopment (2007 and 2018)



Source: Planning Authority, 2019

For this study, various spatially referenced digital data such as zoning maps, road network, temporal data featuring approved requests on sites for redevelopment and a set of geographical boundaries were used. Apart from providing the visualization of the ABM, this data is required for the identification of the zoning factors that attract redevelopment and for the ABM agents to compute and simulate redevelopment. This data was obtained from the Planning Authority (PA) with the LAUs also credited to the National Statistics Office (NSO).

Identifying the most important factors for urban redevelopment

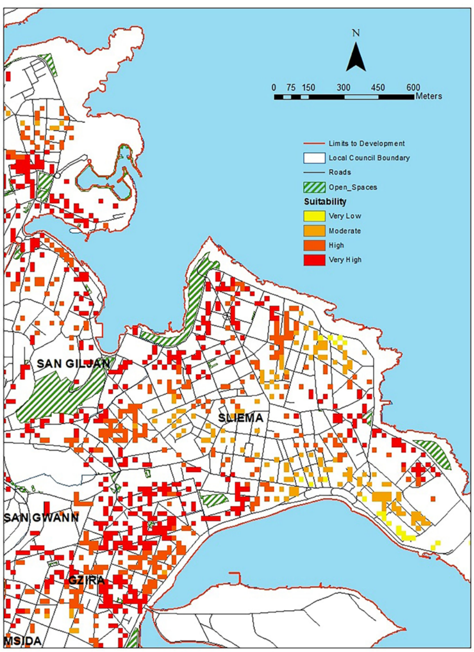
A proximity analysis was carried out based on the closeness of each zoning typology (Adapted from the Local Plans (2006)) and the road network to the redeveloped sites dataset using the near tool. Following the completion of the near distances for each zoning typology, the redeveloped sites point dataset was rasterised. This process was repeated for all zoning typologies. A reclassification process was carried out for each raster to establish similar criteria to each raster (Shahabi & Hashim, 2015). Based on the distribution of data, the rasters produced were reclassified to five intervals - very low, low, moderate, high and very high represent a range of distances in metres and are highlighted in Table 3.

Table 3. Reclassification of Zoning Typologies

Distance (metres)	Suitability
0 – 100	5 - Very High
100 – 200	4 - High
200 – 300	3 – Moderate
300 – 400	2 – Low
400 – 500	1 – Very Low

The five levels of ranking were chosen to easily communicate the extent to which the effect of redevelopment is attributed to a specific distance range. The lower the rank (i.e., 1 - very low) the further away from the zoning typology and therefore, the lower the effect that zoning typology has on redevelopment. Likewise, the higher the class interval (i.e., 5 – very high), the closest distance range to the zoning topology and therefore the higher the affect zoning typology has on redevelopment. An example of the process is highlighted in Figure 2, which shows those sites that are closest to an open space in red and those sites furthest away from an open space zoning topology in yellow.

Figure 2: Classification map for Open Spaces (Northern Harbour)



Urban factors that mostly affect redevelopment - Malta

The highest percentage for each class interval, Table 4, for each zoning typology was highlighted. Based on these findings, the most significant influencers on urban redevelopment were identified (in red). These are listed in Table 5 in order of priority.

Table 4. Percentage of influence for each zoning typology and road (observed data 2007 - 2018)

	Very Low	Low	Moderate	high	Very High
Open Space Areas	1%	1%	30%	30%	57%
Commercial Area	7%	12%	17%	24%	40%
Services	5%	10%	20%	31%	34%
Coastal Area	28%	24%	22%	16%	10%
Historical Areas	21%	23%	24%	19%	13%
Industrial Areas	29%	24%	21%	15%	11%
Areas for Sports	23%	23%	24%	19%	11%
Mixed Use Area	25%	24%	20%	14%	18%
Prime Tourism Areas	23%	30%	21%	15%	12%
Local Roads	0%	0%	0%	0%	100%
Distributor Roads	12%	19%	20%	21%	28%
Arterial Roads	21%	20%	20%	20%	19%

Table 5. Most influential factors that affect redevelopment (Malta and Gozo)

Proximity to:
• Local Roads • Open Spaces • Commercial Areas • Services

Analytic Hierarchy Process (AHP)

The weight of each factor, Table 4, was calculated using an AHP method by means of the Analytic Hierarchy Process for ArcGIS extension (Marinoni, 2017). A Likert scale base on Table 2 was used to complete the pairwise comparison (Table 6). The higher the scale value, the more important the weight is.

Table 6. Priority Matrix (LAUs)

cal Access Roads	68.899	68.899	66.966
Open Spaces	17.073	17.074	18.411
Commercial	8.725	5.303	10.395
Services	5.303	8.724	4.228
CR	0.026	0.026	0

After the evaluation of criteria in the AHP extension, the priority vector is calculated and highlighted in Table 7. The priority vector, also known as normalised Eigenvector, is obtained by averaging the values of each row (Howe, 2015).

Table 7. Priority Vector

Factor	Priority Vector
Local Roads	68.2
Open Spaces	18.74
Commercial	7.836
Services	5.224

The pairwise comparison is derived from a subjective judgement and therefore, it is necessary to check the consistency of the derived weights (Saaty, 1980). The consistency of the pairwise comparison is calculated by using the equation

$$consistency\ ratio\ (CR) \frac{consistency\ index\ (CI)}{random\ index\ (RI)}$$

CI is a deviation of the consistency using the equation

$$consistency\ index\ (CI) = \frac{\lambda_{max-n}}{n-1}$$

where λ max is the average of the priority vector and n is the number of the compared elements, in this case, 4.

Random Index (RI) is the Consistency Index of a randomly generated pairwise comprise matrix, which is dependent on the Saaty scale obtained by (Forman, 1990). Only a consistency ratio (CR) of less than 0.10 is acceptable (Mu & Pereyra-Rojas, 2017). If the consistency ratio is greater than 0.10, it is necessary to revise the pairwise matrix to locate the cause of the inconsistency and correct it. The calculated CR for priority vector for Gozo and Comino and Northern Harbour (Table 6) is 0.026. The CR is less than 0.10, and therefore the inconsistency is acceptable.

Designing and Implementing the Agent-Based Model

The model has been constructed and described in the form of ODD+D (Overview, Design, Concepts and Details) (Müller et al., 2013). Figure 3 shows these entities with the development agents shown as red points superimposed on the environment. The development agents represent heterogeneous individuals wanting to redevelop a site. The model environment is represented by the zoning data, roads data and the limits to development data that bounds and controls the extent where development can happen. The development agent calculates the distance of the agent to the furthest point to the limits of development. The development agents also calculate the distances to the nearest most influential zoning typology, which were identified earlier and listed in Table 5, and the distance to the nearest local road. From these distances, as well as, from the weights established during the AHP process (Table 6) the optimum constructability index is identified using equation below.

$$\text{constructability} = w_{roads} * C_{roads} + w_{open\ space} * C_{open\ space} + w_{commerial} * C_{commerial} + w_{services} * C_{servives}$$

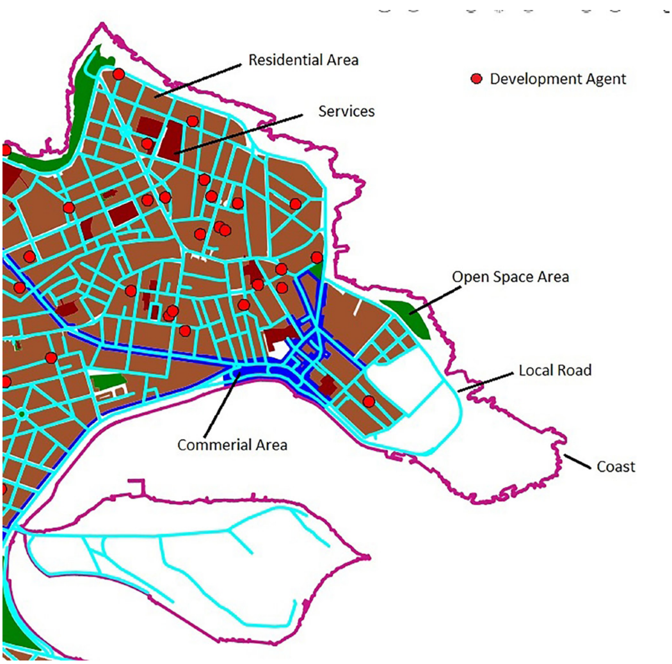
where w is the weights associated with each parameter, which give the importance and attractiveness to each typology and the parameters denoted by C (e.g. C_(open space)) are the normalised distances of each criterion based on the equation below.

$$C_{open\ space} = 1 - \frac{D_{open\ space}}{\max\ \ distance}$$

where D (e.g. D_(open space)) is the distance from the nearest open space zoning typology normalised by the maximum possible distance in the environment max_distance.

If the target location, where the development agent is located, meets that ideal location for redevelopment, based on the constructability index, the agents stop searching. If, however, the constructability index is not met, the agent moves to a new location and repeats the process. This process is carried out until the development agent finds the appropriate location by calculating the constructability index.

Figure 3: The ABM entities, the development agents and the ABM environment



Model Verification

The ABM code was checked against logical errors. The ABM simulated point data was exported as an ESRI shapefile and the simulated distances were checked and verified in ArcMap by comparing the simulated distance with distances calculated using the near tool for the 2018 observed data. Identical distance measurements were noted.

Model Calibration

2018 saw the highest number of approved requests for redevelopment and for this reason, it was decided that the model is calibrated against the 2018 data. This can be done by comparing simulated and observed data using statistics. Given that the simulated and observed data is point data and the scale of analysis is at district level, the importance of how the error varies in smaller areas is not crucial, and hence a visual comparison is satisfactory (A. Crooks, Malleson, et al., 2018). The normalised distances for each zoning typology for the observed 2018 data were calculated in ArcMap for the three LAUs. The standard deviation of these normalised distances was compared with the standard deviation of normalised simulated distances. Table 8 shows the adjusted parameters according to the 2018 data.

Table 8. Calibrated weights

		AHP Value	Standard Deviation (2007-2018)	Standard Deviation (2018)	Calibrated Weights (2018)
Northern Harbour	RD	68.899	0.001	0.001	68.899
	Open Space	17.074	0.009	0.009	17.074
	Commercial	5.303	0.021	0.020	5.050
	Services	8.724	0.016	0.017	9.270
Gozo and Comino	RD	68.899	0.001	0.001	68.899
	Open Space	17.073	0.011	0.011	17.681
	Commercial	8.725	0.022	0.021	8.524
	Services	5.303	0.018	0.018	5.394
Southern Harbour	RD	66.966	0.001	0.001	66.966
	Open Space	18.411	0.009	0.009	18.411
	Commercial	10.395	0.020	0.020	10.395
	Services	4.228	0.017	0.016	3.979

Results

The agents' preference to find their ideal location for redevelopment is based on the model calibrated parameters (Table 8). Figures 4 to 6 show real 2018 data (shown in red) and the simulated data (shown in blue) for the three LAUs. Figures 7 to 9 depict kernel density maps for both real data and simulated date based on the constructability index. The simulated data show similar patterns when compared to the observed data. This pattern is observed across the three LAUs.

Figure 4: Real and observed data (Gozo and Comino LAU)

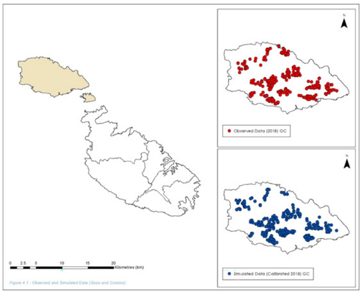


Figure 5: Real and observed data (Northern Harbour LAU)

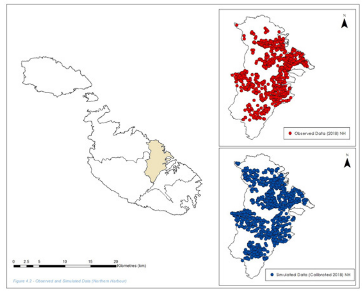


Figure 6: Real and observed data (Southern Harbour LAU)

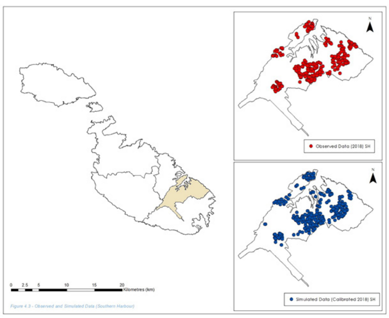


Figure 7: KDE (Gozo and Comino LAU)

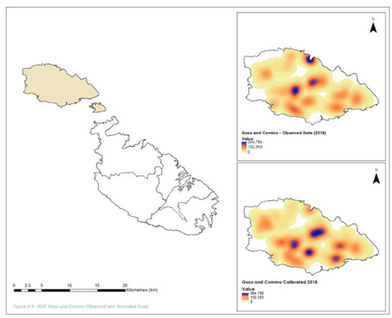


Figure 8: KDE (Northern Harbour LAU)

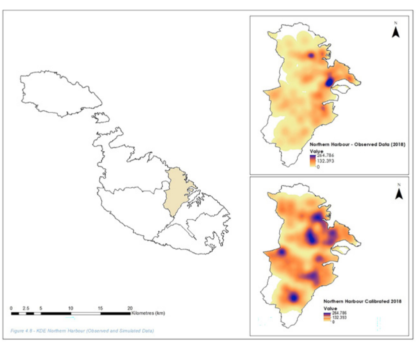
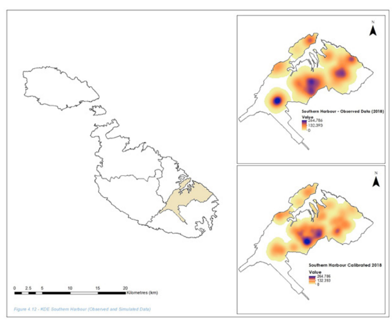


Figure 9: KDE (Southern Harbour LAU)



Figures 10 to 12 show differential maps for each LAU where the kernel data raster for the real data was subtracted from the simulated kernel raster. The significant difference between the kernel density maps is indicated in blue.

Figure 10: Difference KDE (Observed and Simulated Data) - Gozo and Comino LAU

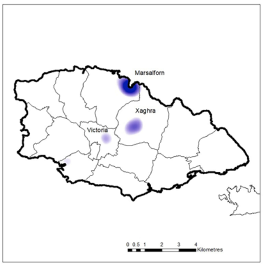


Figure 11: Difference KDE (Observed and Simulated Data) - Northern Harbour LAU

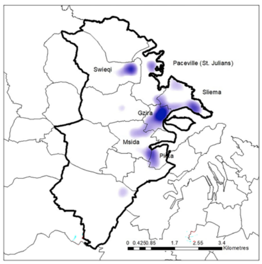
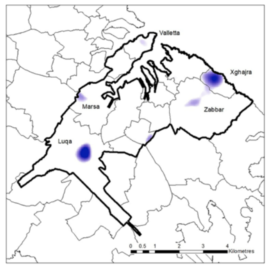


Figure 12: Difference KDE (Observed and Simulated Data) - Southern Harbour LAU



As noted earlier, QQ plots can be used to assess if datasets have normal distribution. A general QQ plot to assess the similarity of the distributions of observed with the simulated datasets using the constructability index as the common attribute for each LAU was applied.

Conclusion

Based on the findings, it is evident that the redevelopment in Malta clusters around good transport network (accessibility), and proximity to open spaces, commercial and services zoning typologies. Studies carried out by Lee and Chan, (2008), Mahamud et al. (2016) and Ghesmi Shah Galdi et al., (2017) reached to the same conclusion. However, while this is the general pattern, some variances across the Maltese Islands were noted. Whereas open space remains the most influential factor for redevelopment in the three LAUs, the weighting of open spaces changes slightly between the three LAUs. Another point noted, is that the scale order also changes between LAUs. For example, services scored a 3 in rank order in Gozo and Comino and Southern Harbour, while in Northern Harbour, services are the second most important factor.

This variance might be attributed to land prices (Zhou et al., 2017). It is not excluded that the rank orders of these factor change from year to year as well. This also proves that even though the Maltese Islands are small, each LAU is diverse in its character. At the same time though it is homogeneous when considering the combination of the same four factors (Table 5) which remain the most significant factors affecting the redevelopment in Malta. In this study, a vector agent-based modelling was presented to model urban redevelopment in Malta. The results show that the model adapted well to replicate the urban development in Malta. This finding is very much in line with what (Crooks (2010) and Taillandier et al. (2016), concluded in their study on vector-based ABMs. that is, a vector model can replicate urban patterns with a certain degree of good fitting to the real data. The model results demonstrate how the representation of urban redevelopment through simple rules governing their behaviour and through the interactions with the environment, can result in recognizable emerging patterns. The behaviour of the agents created a segregation pattern based on the decisions affected by the closest zoning typology.

While urban planning is a complex process, the model results show that agents clustered in areas and how this clustering pattern is observed across the three LAUs. Therefore, even though slight differences between the real and the simulated data were noted, modelling can be regarded as a good way to simplify this complexity by providing a visual representation of the agents in modelled environments (Macal & North, 2011). ABMs are not perfect; however, an agent-based modelling approach is capable of synchronization with the real scenario (Aithal et al., 2016; Leao et al., 2018; Taillandier et al., 2016)

The model results reveal opportunities for further work. The differences between the real and simulated data noted above might be attributed to other factors that are specific for a particular area and which are additional driving forces in attracting urban redevelopment in those areas. It might be that the zoning typology was too generic and needs to be sub-divided further. These differences can be further investigated if the model is set at a smaller scale i.e. at a local council level. Other improvements on the model might be splitting off the zoning typology. For example, residential zoning is sub-categorised to indicate where single dwelling units or multiple dwelling units are allowed. The introduction of the maximum allowable height according to the areas and the property price index might also contribute towards a more realistic model to replicate redevelopment. Making such changes to the model can notably change the decision making of the agents and ultimately the model result. These recommendations might wield additional interesting results.

This study showed that GIS, urban planning and Agent-Based Modelling go hand in hand and can help researchers and planners analyse spatial information during the planning process. The methods and results of this research can be utilised in future studies for even more captivating findings based on the suggested improvements above. The conclusions in this study shed light on the key factors that attract redevelopment in

Malta and through further advancements of this model, urban planners can be better guided when drafting policies.

Note: This paper is published from the author's dissertation as part of the Master's degree in GIS.

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CHAPTER 4

Bridging cognitive gaps in integrated environmental management with remotely-sensed applications

George Buhagiar and Alex Borg Galea

Introduction

Valley management and coastal management, taken in the local context, provide parallel examples where an integrative approach is imperative, and where inherent characteristics of the resources in question, create difficulties in information gathering at spatiotemporal levels. Collectively these two realms make up the country's land domain, but despite the small geographical scale, we still lack a sound basis for planning at the more detailed level due to cognitive challenges. Gaps in information about changes in coastal geomorphology, and about the transient hydrology of valley systems, can create barriers to a more comprehensive understanding of the processes, and the situations to be managed in each of these two realms.

Concepts of integrated environmental management (IEM) have emerged in response to a widespread recognition that piecemeal, narrowly focused or specialised approaches, taken in isolation, lead to fragmentation, whereby problems are shifted or recreated in other forms, instead of being solved. Notions of IEM, in different areas of environmental management, have been hailed as a road towards sustainability. They are founded on the premise that in the real world, 'everything is connected to everything else' and that interdependencies need to be addressed in decision making. A wide range of IEM concepts have evolved in practice, and they are generally shaped by political and cognitive rationales for integration, aimed at overcoming the maladies of fragmented management approaches in different situations (Buhagiar, 2014).

This chapter examines challenges to integration in the cognitive dimension of IEM, in relation to valley management and coastal management, and it explores how these can be overcome by remote sensing techniques. Knowledge gaps resulting from difficulties in data acquisition pose major obstacles to meeting all-important management needs such as: characterising, mapping and modelling change processes, and monitoring and predicting change, for risk management or resource protection purposes. The focus is on data acquisition difficulties that arise from the inherent nature of the resources or hazards being managed.

In the case of valley management, the ephemeral and intermittent nature of Malta's streams makes it difficult to collect data about the relationship between waterflows and the wider ecological balances that they support. Since permanent water bodies are virtually non-existent, and hydrologically transient valleys are the dominant surface water features, the intermittent and ephemeral nature of Malta's watercourses poses major challenges to developing a comprehensive understanding of the fragile ecological and hydrological interactions at play. The need for Integrated Valley Management (IVM) has been gradually recognised but progress has been limited to the generic and wider planning level. The unavailability of spatiotemporal hydrological information undermines planning and guidance to valley management at the more detailed level.

In the case of coastal management for the mitigation of risks from erosion processes, the source and signs of increasing risks are often found in inaccessible or precarious locations. It is difficult to detect, precisely record and continually monitor slight movements in rock, well in advance of the point where they exceed acceptable risk levels. The lack of temporal and spatially wide-encompassing datasets on coastal areas makes it difficult to monitor these processes, and to understand and foresee, critical preconditioning key triggering factors that lead to rock fall. The need for an Integrated Coastal Management (ICM), as a more proactive and holistic approach to coastal erosion risk management has been recognised quite recently in Malta, but initiatives are still uncovering these major stumbling blocks and are facing the challenges of assimilating meaningful data that is useful for risk management of even the most frequently used and higher risk localities.

The first section outlines the methodology used in this chapter for exploring the potential of remote sensing for bridging these gaps in the two management realms. Section Two provides a spectral overview of different remote sensing and LIDAR techniques. Sections Three and Four provide an overview of ICM and IVM in the Maltese context, respectively, explaining cognitive difficulties in each case, and drawing on wider examples to identify how cognitive gaps in each realm can be bridged with specific techniques. In a final section, the chapter draws parallels to bring into focus the transferability and application of remote sensing techniques locally, across the two cases of ICM and IVM. It proposes a heuristic set of parameters as a framework for selection and adaptation of the most appropriate approach for specific needs.

Methodology

Rationale

The aim of this chapter is to examine issues of knowledge and data gaps that emerge as typical barriers to IEM in coastal and valley management in Malta, for the purpose of

(i) identifying the characteristic cognitive challenges to integrated coastal management (ICM) and integrated valley management (IVM) more specifically, and (ii) demonstrating and explaining how appropriate remote sensing techniques can be selected to bridge the particular cognitive gaps of specific management needs in these two realms of IEM.

Four-Step Approach

An overview of remote sensing techniques is first provided, to give a spectral backdrop of different techniques that have been developed over time and used for different situations. Advantages and disadvantages of the different techniques are then summed up as a generic and conceptual guide for identifying the most appropriate techniques for different situations, depending on the accuracy and type of data that may be required, among other considerations. In the next step, the more substantive and specific cognitive barriers that need to be overcome for ICM and IVM, are identified and discussed for each (separately, but in the same fashion in two parallel sections). These are approached starting from the local context for ICM and IVM, to identify the cognitive challenges being encountered. The potential use of remote sensing and its application elsewhere, in different situations like the ones faced locally, is also explored at a general level in these sections, with concrete examples that relate directly to rock fall hazard management and valley management.

Finally, the chapter provides an evaluation about the applicability and transferability of techniques used elsewhere. Here it develops a set of parameters that can be used to plan for, select and adapt a suite of techniques for given situations and their specific management needs. This is done by first examining what are four key management needs for quantitative measurement and investigation – characterisation, mapping, modelling and monitoring – which are impeded by data acquisition difficulties. It is argued that remote sensing techniques, if planned strategically and adopted in combination, can bridge the cognitive gaps and overcome impediments to IEM, being encountered locally in each case. The heuristic parameters proposed in this chapter, on the basis of the two case studies, is intended to assist in the planning of data acquisition for specific management needs.

Remote Sensing and LIDAR – a Spectral View

This section will first outline the most common of a wide range of techniques that have multiplied in number and developed in accuracy over time, and then summarise and compare their strengths and weaknesses. This will provide a critical and intuitive perspective to their qualities and adaptability to meet particular management needs, explored in more detail for ICM and IVM in the two following sections.

Range of Techniques

Two generic subdivisions may be made to categorise and understand the range of types of remote sensing and other investigation and measurement techniques that can be applied in combination. Firstly, data acquisition can be terrestrial or aerial based – depending on the location of the data acquisition instrument (ether ground-based or from the air). Meanwhile terrestrial (or ground-based) data acquisition can itself be either area-based or point-based – depending on the extent of the object of inquiry, about which data is captured (an area or specific points). For instance, laser scanning has been developing in two main ways, depending on the position of the sensor: airborne-based for ALS and ground-based for TLS (Kenner et al, 2014).

Photogrammetry and **geodetic surveys** "can be regarded as classical techniques for monitoring the surface dynamics of ground movements. Photogrammetry provides sufficient spatial and – in case of a good data base – temporal resolution" (Kaab et al., 1997; Kaufmann and Ladstadter, 2009).

Geodetic surveys are land-based and "cheaper to carry out but implicate a lower density of measurement points on the surface" (Kaufmann et al., 2006).

Differential GPS (DGPS) "is a further terrestrial method which is increasingly used for monitoring purposes although it has the same spatial drawback as geodetic surveys" (Lambiel and Delaloye, 2004).

Digital Aerial Photogrammetry (DAP) and Structure from Motion (SfM) are used to build 3D point clouds and to render them from the colour images, to create scale visual models.

Digital Elevation Models (DEM) are then built from these datasets, which when captured intertemporally, enable the respective DEMs to be used to determine characteristics of mass movement processes such as accumulation and deposition of material, volume estimates or the orientation of discontinuities.

LiDAR or **Laser-scanning** is a very widely used and important method in remote sensing and has been developed into various techniques. LiDAR stands for Light Detection and Ranging, while the acronym LASER stands for Light Amplification by Stimulated Emission of Radiation. A laser is a device that produces and emits a beam (or a pulse series) of highly collimated, directional, coherent and in-phase electromagnetic radiation. Both airborne and ground-based sensors send out laser pulses that get back-scattered by various objects (ground surface, vegetation, man-made constructions etc.) and record the returning signal. LIDAR (or laser scanning) "provide high-resolution point clouds of the topography and has several applications that range from mapping" (Ardizzone et al. 2007; Jaboyedoff et al. 2008a) to monitoring deformation (Gordon et al. 2001), landslides or rockfall displacements (Teza et al. 2007; Oppikofer et al. 2008; Abellan et al. 2010) to landslide in soils (Jaboyedoff et al. 2009a).

Helicopter-based "ALS can give a higher resolution than aircraft-based ALS and especially allows orientating the scanner in all directions" (Vallet and Skaloud 2004). The parallel development of unmanned aerial vehicles (UAVs), or drones, is also multiplying the possible options for closer range, more frequent and affordable, aerial modes of data acquisition. Both the UAV-airborne (ALS) as well as terrestrial (TLS) are relatively recent techniques, compared to the above geodetic, surveying and aircraft-borne photogrammetry methods.

Terrestrial Laser Scanner (TLS) instrumentation "is also known as a Ground based LIDAR. It records "real changes" in certain parts of the slope, e.g., rockfalls, vegetation growing, etc. Sign criteria are employed, using positive values when the time of flight of the laser signal is greater, when compared to an earlier dataset. Thus, positive values correspond to a lack of material at a given point, i.e. detachment of the material. Likewise, negative values correspond to an increase in material or erosion of other areas, i.e., scree deposits, sedimentation, or vegetation growth" (http://www.nat-hazards-earth-syst-sci.net/). The 'negative' displacement is notable for monitoring purposes in steep terrain, as it indicates swelling or enlargement, and has been interpreted as an indication of bulging that could be indicative of failure processes (Abellan et al., 2009, 2010).

To create DEMs, point cloud data can also be provided by terrestrial laser scanning (TLS) and this has been recently used, in combination with other more traditional forms of remote sensing, for analysis of mass movements to higher levels of accuracy (Prokop and Panholzer, 2009).

TLS usage has gained popularity "at the beginning of this decade and allows acquiring 3-D surface data with a high spatial sampling rate. Long-range TLS (well above 400 m) is of particular interest for measuring" non-accessible areas as it offers very detailed digital surface models of terrain from a distance (Bauer et al., 2003; http://www.nat-hazards-earth-syst-sci.net/). "The latest instruments, with a measuring range of up to 2000m or more, allow remote and hazardous sites to be easily measured from a safe distance. The typical accuracy of the laser instrument is ±1.5 cm, within maximum distances of about

800–1,000m" (Manetti and Steinmann 2007). Nevertheless, the instrumental accuracy is usually lower in practical applications due to unfavourable conditions such as: poorly reflecting or very rough surfaces, parallel incident angles, bad weather conditions (rain, hot wind or fog), very bright ambient conditions, or excessive range.

TLS provides high resolution, adequate accuracy and high availability over long periods of time at comparably low cost. Nonetheless, in terms of measurement accuracy, the availability of independent measurements is a crucial factor to validate the acquired data. Stable bedrock areas – forming "natural targets" are also required to provide reliable reference points for detecting changes via the temporal point clouds derived periodically from the sequence of TLS data sets (Pradhan et al, 2012). In some cases, such vantage points are not available, and the resultant point clouds may suffer from areas of unscanned terrain which may be pocketed between rugged topography or obscured by vegetation. Such limitations can be overcome by helicopter or drone-mounted ALS, which can cover particular spots more directionally than aircraft borne ALS, but always with lesser resolution than TLS.

Remote sensing from space is another continually advancing area of data collection that has opened unprecedented sources of information, as more satellites are launched and kept on the move. European Space Agency (ESA) archives, which can be used in such studies, span over more than 20 years enabling the carrying out of retrospective research. (Mantovani et al 2013, 2016), which is very useful mapping slow-moving changes.

Major advances have also been made in satellite-borne (or space-borne) remote sensing (Kenyi & Kaufmann 2003) and in combination with the use of aircraft (Baltsavias 2001), aerial photogrammetry (Kaufmann & Ladstaedter 2003), and with the availability of high-resolution optical remote sensing (Kääb 2002). Change detection using SAR (synthetic aperture radar) imagery is possible up to a height resolution of a few cm (Sharov & Gutjahr 2002).

Interferometry is another relatively recent and fast-developing measurement technology that is versatile "for examining surface topography with very high precision" (cmi.epfl.ch). In most interferometers, light from a single source is split into two beams that travel different optical paths, then combined again to produce interference. Under some circumstances, two incoherent sources can also be interfered (Patel et al, 2014). Interferometry actually includes a family of techniques in which waves, usually electromagnetic waves, are split, superimposed and compared, causing the phenomenon of interference in order to extract information (Hariharan, 1996).

Interferometry has been developed as "an important investigative technique in the fields of remote sensing (among other fields ranging from oceanography, seismology to quantum mechanics and biomolecular interactions) and is widely used in science and industry for the measurement of small displacements" (en.wikipedia.org). Interferometers are instruments that can also provide dynamic measurement capability, such as the analysis of resonant frequencies of structures, three-dimensional motion mapping, and more (Creath, 1993; Larkin,1996; Harasaki et al, 2000). Interferometry is not a technique used solely in isolation, but is also applied in combination with other methods. It is used in combination with space-borne remote sensing, for example, to monitor slow movements in topography and material changes in its surface. Space-borne differential synthetic aperture radar (DinSAR) interferometry offers very accurate measurements especially of (cm to mm) vertical surface displacements (Kenyi and Kaufmann, 2003).

The latest space-borne interferometric missions (e.g. COSMO-SkyMed, Terra SAR-X and sentinel) will increase the spatial and temporal coverage, providing datasets with unprecedented resolution that will certainly favour the implementation of interdisciplinary approaches to the monitoring of changes in topography and geomorphology. (Mantovani et al, 2016).

Single point GPS measurements are also generally used to observe the kinematics of spatially limited areas and to obtain precise point-based reference data for TLS/ALS datasets to increase their accuracy (Lambiel and Delaloye, 2004).

Capabilities for Different Uses

The strengths and weaknesses of different remote sensing techniques need to be considered against the particular investigative need and management measures which the data acquisition is intended to support. A number of criteria (Kenner et al, 2014) are useful in this regard, but it is still highly recommendable to carry out an evaluation of applicability of the different methods in every single case, taking into account the specific site conditions, and carrying out testing and control studies to ascertain that the required degree of accuracy and focus on required attributes is being achieved.

Table 1: Strengths and weaknesses of three different remote sensing techniques used

	DAP	ALS	TLS
Accuracy	>dm	>dm	>cm
Resolution	>dm	<m	>dm
Shadow effects	in very steep terrain	no influence	strong influence
3 Dimensionality	indirect in lower quality	directly	directly
Natural radiation	dependent	independent	independent
	(shadows/different lighting)		
	condition		
Costs (equipment/ application)	very high	very high	high
Range	national	regional	local
Time series	often several decades	short	short
Image information	direct and exact	possibly indirect	possibly indirect

(Kenner et al, 2014)

Most of the methods of DAP and ALS rely on sensing from nearly vertical viewing angles which means that steep slopes can only be covered with strong restrictions in measurement performance, if at all, but van be partly overcome with the use of UAVs. This applies equally to coastal areas and valleys. Moreover, when front slopes are not undergoing rapid change in shape, texture and object distribution, it becomes difficult to detect processes of slow sliding debris, small rock fall, and accumulation of material (in coastal areas) or bank erosion, sedimentation and infilling of water retentions behind dams (in valleys).

In the case of coastal erosion, the respective changes could be precursory of hazardous and more sudden change events. In the case of valleys, the respective developments can indicate decreasing levels of flood relief or diminished water conservation capacity.

Therefore, the limitations of DAP and ALS, may cause standard change detection strategies to fail, and they would have to rely on a high use terrestrial laser scanning technology to overcome these problems, where, on the other hand, the ability to forewarn of these concerns (in both valleys and coastal areas) will be highly dependent on the frequency and regularity, as well as the timing of the data capture. Another disadvantage of DAP and ALS methods is the necessity to have reference targets for sensor orientation. Current research tends to solve this problem with natural targets, as Ground Control Points (GCPs).

A monitoring campaign using TLS techniques was applied to displacements prior to the April 2007 rockfall event at Castellfollit de la Roca, Spain, for the detection of millimetric deformation (Abellan et al, 2009). In this particular situation, (where retreat of the cliff is rather significant, as noted earlier) precursory patterns in wide areas could be detected using TLS (Rosser et al, 2007). The addition of GCPs with TLS use enhances its accuracy, while combination with Interferometry also provides additional benefits of ease of data capture and higher accuracy. Interferometric systems have been successfully used to investigate dispersion of materials, complex indices of refraction, and thermal properties, as much as to measure small dimensions at large distances. In landslide investigation, TLS and ALS, in combination with interferometric synthetic aperture radar (InSAR) have become increasingly common (Fruneau et al. 1996; Colesanti et al. 2003; Squarzoni et al. 2003), with light detection and ranging (LIDAR) (Carter et al. 2001; Slob et al. 2002; Haugerud et al. 2003; Slob and Hack 2004).

While LIDAR intensity provides only some information on the material type, and it remains a difficult task to discriminate different materials (e.g. lithologies) based on the laser reflectivity, it has been applied with good results to the classification of river beds at different epochs by identifying water–land boundaries (Hofle et al. 2009), which is certainly useful for valley management. Some research groups are now looking at further refinement of LIDAR imaging coupled with other remote sensing techniques. LIDAR data sets merged with RGB colours obtained from optical camera were tested on the Vesuvius crater providing encouraging results, but research is still far from an operative one (Pesci et al. 2007, 2008). Coupled with LIDAR data sets, the hyperspectral camera permits to get additional information on ground characteristics (Kurz et al. 2008).

Combined with the use of infrared cameras that can pick up thermal signals and water content, these applications can thus be used for identification of subsurface water or vegetation types – data which is relevant both for the stability of coastal areas, and for watercourse management. Data gathered about transient streams and ground moisture, through specialised remote sensing imagery, can be used to monitor the delicate balance between hydrology and vegetation growth, water course obstructions and the proliferation (or loss) of specific biota and ecosystem health in specific areas, in the more challenging transient streams, where locally-controlled drone deployment can overcome limitations of given flight programmes and issues of scale.

There is clearly no single technique that can meet all investigative needs in different situations. A combination of techniques is also most likely to be best suited to address key management needs for investigation and measurement of processes and changes in the real world, to characterise and map patterns virtually, to enable their modelling, monitoring and eventually their prediction, as a basis for management decisions. Prior to discussing these management needs more specifically and identifying parameters that can be considered for planning data acquisition with the most appropriate suite of remote sensing techniques, the next two sections will discuss in more detail the cognitive challenges that can be overcome thus, in the two case studies of ICM and IVM.

Integrated Coastal Management

Relative to their small size, the Maltese Islands offer a very diverse and interesting coastal geomorphology. When compared to other natural public spaces, the coastal area, as a public domain, is possibly the most frequently visited and intensely used, by tourists and locals alike. Different coastal areas are generally visited for different recreational and other activities. However, a significant number of popular locations pose unnoticeable risks from rock fall induced by coastal erosion and geomorphological processes.

Geological and climate processes that have, over the ages shaped the coast, giving it its presently high value to people. These same processes are unrelenting and unstoppable and bring about changes that can be a cause of harm to unsuspecting visitors or occupants of these areas. Risks and hazards are the result of the coming together of people and ongoing geomorphological processes. Coastal Erosion Risk Management (CERM) requires an ICM approach to encompass the various facets of natural processes and their impact on social wellbeing.

The Local Context of Coastal Erosion Risk Management

The approach to the management of risks from coastal erosion hazards in Malta has, up to the very recent past, been predominantly reactive, whereby an area is commonly hoarded off after being identified as dangerous following incidents of rock fall, or when the state of the rock has become obviously precarious. A more integrative approach to this aspect of coastal management is being sought to enable authorities to better monitor processes and dynamics, and to take more proactive remedial or risk mitigating measures, before unacceptable risk levels are reached. However, the unavailability of knowledge and information for reliable monitoring, to attain a sound understanding of the processes creating risks in particular areas, is proving to be a cognitive challenge that is creating a barrier to the much-needed integrative and proactive approach to this issue.

Risks are created by different processes of movement or erosion in combination with triggering factors. Particular areas may also be preconditioned to landslide or rock fall, or other processes that can cause harm or damage. Management of risks from such unstoppable phenomena, involves assessing hazards, mitigating the risks or coping with the hazards. As of primacy, this requires an understanding of the processes and dynamics at play. This is a prerequisite for foresight of when and where the next incident is likely to happen, and also of the likeliness of such occurrences. However, such a comprehensive understanding requires a wide-ranging vision that can only be attained with vast and encompassing data acquisition and information gathering - -which can prove to be a major cognitive challenge to IEM in this realm – especially given the relatively inaccessible and hostile terrain, source of the risks to be managed, and main object about which data acquisition is required.

Cognitive Challenges to Understanding GeoHazard Processes

One of the present and foremost challenges in rock fall hazard is combined temporal and spatial prediction of rock falls (Abellan et al, 2009), which may be in many forms such as cliff and slab collapse, landslide, or falling debris.

Towards a Process-Oriented Reference Concept of Risk

A foremost concern is identifying the origin of risk. This requires not only knowledge that enables the identification of the type of mass movements (rock fall, landslide, slab detachment or other types of collapse) described by Cruden and Varnes (1996). It requires insight about the processes linked to these phenomena.

From a risk assessment perspective, the general guide and broad reference proposed by Jaboyedoff et al, (2012), is useful in that it identifies three important processes, namely, 'rockfall', 'landslides' and 'debris-flows'. However, this is derived from a study of mountainous and glacial terrains, where movements are characteristically faster than what is encountered locally because of coastal erosion or more gradual shifts in the geomorphology of coastal areas, locally. This reference framework can be refined into one which can be used in the local context for coastal erosion risk management. The origin of coastal erosion risks can be conceptualised as consisting of four component elements which, when acting in combination create or increase risk in a specific area.

Adding a fourth type of process, as an agent of change, they can be seen as a set of wider interlinked processes, providing a more integrated, yet analytical understanding of the overall dynamics of risk origins:

1. ’rockfalls’ occurring as a result of instability, detachment and propagation of rock; A ‘rockfall’ has been defined as a fragment of rock detached by sliding, toppling or falling and which falls along a vertical or sub-vertical cliff and proceeds down slope by bouncing, rolling or sliding (Varnes, 1978);
2. ‘landslides’ referring to all areas where the material undergoes large-scale movement, at sudden, relatively fast, or slow rates of collapse or deformation;
3. ‘debris-flows’ referring to slope movements formed by debris type of material, moving down the slope as a flow, and;
4. ‘deformation’ caused by weathering erosion and slow geomorphologic processes, which alters the shape or orientation, creating a resultant instability that may lead to rockfalls, or continuous dynamics that are manifested in landslides and debris falls.

The above four components are interconnected and can be consequential of one another and, often, act in combination. Ultimately, it is the incidence of one or more of the first three of these processes that results in harm to people. But understanding the origin of geohazard risk, as way towards managing for its mitigation, requires this process-oriented reference concept of risk origins. For instance, the phenomenon of platform formation in limestone strata, where the retreating cliff face creates perched ledges is common in significant parts of the Maltese coastline (Soldati, 2016; Devoto et al, 2012).

Hazardous areas are created by cliff-face surface erosion over time, as ledges formed by deferential deformation eventually crumble and create risks to anyone on the shore platform below. These areas are not uncommon in the South of Malta in locations such as Delimara, Xrobb l-Għaġin and St. Peter’s Pool. The same features also offer shade and attract sunbathers. These areas can be regarded as rock fall hazard areas created by erosional deformation over time, but which pose a risk to safety as a result of use of the area.

Extensions of the fragile Upper Coralline rock mass over softer underlying clayey strata is typical of the geological profile in the Northwest of Malta. This is undergoing a slow but continuous displacement along an undefined basal shear surface, referred to as lateral spreading processes with rockfall and debris falls (Pasuto and Soldati 1996) which are a result of the ‘deformation’ process. Despite their slow speed rates, these terrain deformation phenomena may cause damage to human structures and favour or trigger collateral faster movements such as falls, topples, slides and flows (Soldati and Pasuto 1991)

Preconditioning and Triggering Factors

In understanding the natural processes that play a part in creating hazard situations, it is important to identify the role of critical preconditioning and key triggering factors, nested within the overall process-oriented reference concept of risk origins. It is necessary to take a multi-level interdisciplinary view to what makes a rockfall happen because understanding the geomorphological processes and risk origins is only part of the initial steps for risk management. It is crucial to then also identify the presence of preconditioning factors, and the action of other triggering factors These can act in combination and lead to the occurrence of one or more of the risk-creating processes (rock fall, landslide, debris) that may take occupants of an area unawares or cause damage over time.

A multidisciplinary and multi-technical approach is required to provide a better understanding of the causes, mechanisms, state of activity and evolution of a complex mass movement, involving processes such as rock spreading, block sliding phenomena, rock fall or slab collapse (Devoto et al, 2012). Within the overall process-oriented framework for identifying what occurrences create risk, identifying when and how these occur requires a recognition of the preconditioning and triggering factors that bring them about. A somewhat recent geomorphological survey and mapping exercise, undertaken along the north-western coast of the Island of Malta was carried out as part of a research project aiming at the assessment of geomorphological hazards in the area. The study shows that the morphological features in the study area are strictly controlled by structural factors and modelled by gravitational, coastal and karst processes. In particular, the area is largely characterised by the occurrence of landslides which are favoured by structural conditions and triggered by rainfall and marine erosion (Devoto et al, 2012).

The combination of several (i) conditioning and, (ii) triggering factors may be identified as being 'nested' within the wider process-oriented reference framework of risk origins, described above, for a better spatiotemporal understanding and identification of risks in particular areas, according to their given geomorphology. Conditioning factors are characteristics that may predispose one area to risk, more than another, and these relate to inherent structural features (Source: https://nhess.copernicus.org/articles/index.html):

1. pre-existing joint patterns: determined by the geometry of material layering, will influence the mode of detachment from the provenance area;

2. layout and composition of lithological units: these structural features precondition the patterns and intensity of erosion and/or weathering preferences at different levels and shape overhangs in the upper levels, affecting their stability, as in the case of interconnected rock falls; and
3. the morphology of the cliff: that may affect the local stability of the rock face, for instance, making the protruding parts of the slope very unstable, or weak and likely to collapse with the slightest load.

On the other hand, triggering factors can include:

1. the role of precipitation in the occurrence of rockfalls;
2. the erosion of the scree deposits and/or of the lower part of the rock face; and
3. finally, an area may be located in a seismic area. Even at low recurrence frequencies, or medium to low magnitude, seismicity has also been regarded as a triggering factor in landslides (Abellan et al, 2011)

All aspects in a given situation –both conditioning and triggering factors – are nature-driven processes. When it comes to the management of risks to people; such factors must be considered in combination with the human-exposure parameters. Therefore, an extensive spatiotemporal capture of data is required to monitor and understand these processes in combination with data about the use intensity of such areas, to arrive at an assessment of risk, since as noted earlier, issues of coastal erosion risk management are created not by natural processes alone but by the coming together of people and ongoing geomorphological processes. The major challenge to hazard management is determining when a particular process or incident will take place since this is dependent on other processes, a quantitative approach is required to determine risk levels, but this may be a daunting task to achieve with a level of accuracy which can, with confidence, deemed as reliable for people's safety.

Data Acquisition Challenges as Barriers to Understanding Processes

A quantitative interpretation of lateral spreading evolution and its relationships with collateral landslides are fundamental in terms of risk assessment and possible mitigation strategies (Mantovani et al, 2013). Likewise, quantitative and precise data is required about those features of the particular geology of any area. It is necessary to continually take measurements, in such a way that the data collection can be meaningful and telling, in terms of modelling movements and predicting patterns of collapse, and most importantly to anticipate events of collapse. The major challenge to hazard management is determining when a particular stage in a process, or incident, will take place since this is dependent on other processes, a quantitative approach is required to determine risk levels, but this may be a daunting task to achieve in terms of identifying the limits/thresholds for occurrence, with a level of accuracy that is deemed as reliable with confidence.

The use of different methods and disciplines is required to collect such data sets. Three main challenges can be identified with regard to taking regular accurate measurements in risk-prone areas:

- the remoteness or hazardous nature of the areas about which the data is required;
- the long term and regularity of data collection required, given that processes are relatively slow, providing an understanding of the processes requires more than a few snapshots: and
- the level of accuracy to record the changes in question, to provide meaningful data that can tell the difference between real changes and any errors inherent in the data collection methods, computations or instrumentation use to measure changes.

Bridging Different Needs of Geohazard Management

This section provides a view of what can be done, and what has been done, using a series of examples, taken from Norway southwards across Europe and down to Malta, where the above cognitive challenges are being overcome. These demonstrate how the use of one or more techniques has been used and tested for the monitoring and evaluation of ground movements for hazard management.

Western Norway – rockslide monitoring

Terrestrial laser scanners are a key tool for characterization and monitoring of the Aknes rockslide. In Norway, large rockslides causing catastrophic tsunamis in the narrow fjords are frequent. In 1934 a 2–3 million cubic-meter Tafjord rockslide led to a catastrophic tsunami with a run-up height of more than 60m, killing 40 people. The Aknes rockslide, situated in Western Norway is now one of the most investigated rockslides in the world. A large variety of techniques are used to include measurements of potential triggering factors including meteorological, seismic and groundwater conditions (Blikra et al., 2006a; Blikra, 2008; Roth and Blikra, 2009). Some of the displacement monitoring techniques used are point based (GPS, extensometers, total station, and laser distance meters), while others are area based (photogrammetry, satellite-based and ground-based radar interferometry, ALS and TLS.

The knowledge of the displacement rates is essential for hazard assessment (Crosta and Agliardi, 2003), especially for the evaluation of volumes, failure prediction, and assessment of the tsunami hazard. More important for landslide hazard assessment and landslide monitoring is the potential of TLS to detect global slope movements over the whole landslide area and not just at single monitoring points. Terrestrial laser scanning (TLS) has been employed to provide high resolution point clouds of the topography, where the measured slope movements reach about 1–3 cm/year (Braathen et al., 2004). At 100 m, the instrument accuracy equals approximately 7mm for the distance and 8 mm for the position.

Austria – Assessment of TLS Accuracy for Monitoring Slow Moving Landslides

The area of the "Galierm" landslide is located northeast of the town of Schruns in the area of Montafon (Vorarlberg, Austria), above the bank of Litz stream. A high water event at the Litz stream in 2005 caused significant erosion of the bank. A weak section of the stream bank initiated significant movement of the slope section over an area of approximately 100m × 100m. The reliability of TLS data was investigated in a comparative study with tachymetry, to assess its ability to determine movement patterns of landslides of the order of less than 100mm. Between March 2006 and September 2007 six data acquisitions in a time interval of approximately 5 months using both measurement methods, terrestrial laser scanning and tachymetry, were executed to monitor the moving slope, "Galierm".

The study concluded that using standard GIS tools for filtering applications, it was not possible to determine movement rates <50mm and that if higher accuracy is required for monitoring project of slopes having vegetation cover, then manual filtering was a must, to reach accuracies of 51 mm, otherwise automated filtering reached only 127 mm accuracy levels. (Prokop and Panholzer, 2009; https://nhess.copernicus.org/articles/index.html).

In another location in Austria, TLS has also been found to be a relevant technique for rock glacier monitoring. The Hinteres Langtalkar rock glacier and the Pasterze glacier are in the Hohe Tauern National Park in the Austrian Alps. The full end-to-end chain of rock glacier monitoring, was able to track change between August 2000 and August 2001 using a long-range terrestrial laser scanner. Small debris falls as well as accumulation of debris and scree were also detected, while the local mass movements could be evaluated down to single cubic meters. (Bauer and Paar, 2003)

The DTM of rock glacier Hinteres Langtalkar delivers a spatial resolution of 1 m and surface roughness is sometimes represented fairly accurately (with boulder sizes exceeding the spatial resolution) or only approximated (smaller boulder sizes, small cracks). Comparing across two study periods, mean surface elevation changes have been noted to be repeatedly positive over the entire observation period with 75cm (2000/2001) to 30cm (2007/2008) of surface elevation changes. During similar periods in between, other changes as small as 10 to 20cm were recorded in the marginal area (Avian et al, 2009).

Swiss Alps - Combined use of DAP, TLS, ALS and GPS

Rock glaciers are the visible expression of cumulative deformation by long-term creep of ice/debris mixtures under permafrost conditions (Berthling, 2011). They displace large volumes of rock debris–ice mixtures downslope at rates typically varying between several decimetres to metres per annum (Harris et al., 2009).

It is argued here that although this example comes from a completely different climatic and geomorphological context, some parallels can be drawn with the land sliding and lateral spreading processes encountered in the Northwest of Malta, at least at the level of the way in which such mass movements may need to be, and possibly can be, monitored using the combination of these methods, but requiring a greater degree of accuracy. The temporally and spatially variable, and sometimes quite unforeseeable, nature of rock glacier dynamics is particularly relevant in the triggering of rockfalls and debris flows from the snout (Lugon and Stoffel, 2010). Like the slower moving landslides in the Northwest of Malta, the active rock glaciers and landslides are also the source of further high intensity sediment transfer processes such as 'rockfall' and 'debris flows' that have significant occurrence risks and must be monitored efficiently and quantitatively for successful hazard management (References: doc.rero.ch).

In the Swiss Alps, mass movements were measured using combined remote sensing methods of DAP, TLS and ALS, in order to develop an accurate and monitoring technique. The combination of orthophotos and laser scanner data is useful to detect horizontal deformations of 25 cm or more at the Grabengufer site. For changes with an extent of about 25 square meters, a level of significance of 3 cm was obtained for both horizontal and vertical displacements under optimal measurement conditions (Kenner et al, 2014). While this level of accuracy may be deemed satisfactory for mass movement recordable on this scale, it may require further refinement to achieve accuracy that can record much smaller displacements that are typical of the lateral spreading and rock mass failure, in the Northwest of Malta, which are of a millimetric scale.

France –monitoring of hostile landslide ground

Terrestrial Laser Scanner (TLS) is also widely used and found to be an appropriate technique for the monitoring of the Séchilienne Landslide in Isère, France (Kasperski et al, 2010). The Séchilienne landslide is located on the north side of the Romanche valley, 20 km southeast of Grenoble (France) in the French Alps. The three million cubic meters of rock in the active zone named Ruines, have the potential to prododuce debris that would dam the Romanche valley. The active Séchilienne landslide (Isère, France) has been continuously monitored, initially by tacheometry, radar and extensometry devices, for more than 25 years. The monitoring system, initially composed of geodetic and extensometer manual measurements (cables stretched through fractures), was developed gradually (Kasperski et al, 2010) into the multi component monitoring campaign it is today. It has been improved, more recently, with spatially wider and more encompassing coverage, with the development of new technology that enables datasets from hazardous terrains to be collected with unprecedented ease and accuracy.

The sequential TLS datasets and DEMs subtractions now provide an accuracy of 250 mm, enabling a spatial determination of the moving zones. Object recognition based on 2D transects in the main direction of displacements, provide quantification of displacements with a precision of +/−30 mm in all directions. Limitations encountered included the position of accessible points of view; and as they are not completely frontal, some point clouds suffer from shaded areas created by vegetation and chaotic zones, thus still preventing full coverage of the spatial analysis, and possibly missing out on important information.

Catalonia, Spain – Rockfall Monitoring by TLS

The village of Castellfollit de la Roca (Catalonia, Spain) is located at the top of a Quaternary basaltic formation bounded by two scarps. The rockfall and hence the rock face retreat could pose an important risk to houses located on the edge of the fifty-metre-high cliff. A study was carried out between 2006 and 2008, utilising TLS for monitoring rockfall. Sequential TLS datasets were used to provide a complete coverage of the surface, which has enabled a morphological characterization of the rock face over time, as well as the identification of the location and volume of rockfalls. The use of TLS provided a better understanding of the spatio-temporal patterns of rock fall phenomena, in terms of both the loss of material, in terms of volume and thickness at located points, as well as deformations, picked up as negative displacements, which may reflect pre-failure deformation in a part of the slope (Abellan et al, 2011).

A continuous, set of real-time TLS records, in combination with recording of the respective parameters, would provide a far better understanding the triggering and preconditioning factors, noted above, if changes or specifics can be correlated with rockfall events on a more consistent and coherent spread of the respective attribute data. To this end, a monitoring period longer than that employed in the Castellfollit de la Roca (Catalonia, Spain) study is needed to obtain a more accurate record of small and large time-scale events; and to quantitatively measure and model their movement patterns that precede such failures with any degree of confidence.

Northwest Malta – use of PSI for slow moving landslides

Persistent Scatterers Interferometry (PSI) techniques are widely employed in geosciences to detect and monitor landslides with high accuracy over large areas, but they also suffer from physical and technological constraints that restrict their field of application. These limitations prevent us from collecting information from several critical areas within the investigated region (Piacentini et al, 2015). The north-western coast of Malta can be considered as an open-air laboratory for the study of lateral spreading phenomena, namely rock spreading, due to the peculiar geological geomorphological setting related to the presence of extensional faults and to the over position of rock masses overlying clayey strata, altogether characterised by different geomechanical properties (Mantovani et al, 2013).

Resistivity Tomography profiles and GPR investigations have been carried out to identify main structural discontinuities and to reconstruct variability of underground surface contact between clays and overlying limestones. Both point-based and area-based monitoring techniques have been employed on this site. Point based techniques include the use of fissure meters and GPS while remote sensing has been used for wider mapping, in combination with extensive use of interferometry.

The combination of these methods has been capable of measuring millimetric changes in lateral sliding and block movements in the area known as Il-Prajjiet. It can be applied for land management purposes, to assist in hazard mitigation and contribute to decreasing territorial vulnerability. PSI represents the only existing technique that can quantitatively assess the state of activity of landslides at a regional scale with an acceptable cost/efficiency ratio, at this level of accuracy where the maximum displacement recorded may be of the order of 1 cm in a decade, and even less in marginal areas of block slide mechanism (less than a millimetre in a year).

Northwest Malta –Exposure Dating with Cosmogenic Data

Dating landslides is important for determining rates of meso-scale erosion in the landscape since mass wasting constitutes one of the major geomorphological processes in landscape evolution of mountain, coastal and submarine environments (Soldati et al 2018)., referred to as 'deformation', earlier on. Exposure dating using cosmogenic nuclides (especially Be and C1) is now one of the most commonly employed techniques for dating landslides. The results from exposure dating performed on block slides located along the north-western coast of the Island of Malta provide the first long-term chronological constraints on their geomorphological evolution and they highlight the fact that such blocks were not detached recently, pointing to their time of detachment to around 21,000 years B.P. (Soldati et al 2018).

The aims of investigation and measurement are somewhat similar, all attempting to characterise, map and model processes in a bid to better manage the risks associated with such natural processes. The recording of movements and deformations is approached with the use of different remote sensing and other techniques in the range of examples outlined above. This begs the question as to how to plan with the the most appropriate techniques for data acquisition in a given situation and which techniques are most suited for the local conditions. The next section provides a similar exploration of cognitive challenges that can be overcome by remote sensing in another realm of environmental management, before drawing parallel and attempting to provide a guide for these important questions.

Integrated Valley Management

Valley management is a topical issue because while valleys cover te inland areas and provide an environmental service as a conduit of water runoff, decades of neglect, misuse and overdevelopment have compounded and created a two-fold problem to wellbeing – with catastrophic flash flooding in downstream areas and radically diminished percolation and ever-increasing water scarcity. The temporal nature of Malta's main surface water bodies makes it more difficult to build a comprehensive understanding of the practically immeasurable and hydrologically transient valleys of the Maltese Islands. This poses major challenges to developing a comprehensive understanding of the fragile ecological and hydrological interactions at play.

The Local Context of Valley Catchments and their Management

Valleys ubiquitously adorn the landscape of the Maltese Islands. They form drainage channels moulded either by stream erosion during the wetter Pleistocene period or by tectonic processes or by a combination of the two (Schembri, 1993). The limited average rainfall of 553.12mm (Galdies, 2011) and absence of mountains mean that most of them are hydrologically transient. Their flow regime pattern is temporally and spatially varied and can be classified into two categories: (i) ephemeral dry; which are streams that only flow subsequent to rainfall events and have a hydrological continuity limited to a period of time, usually ranging from days to weeks, and; (ii) intermittent; which are streams that also characterised by geology since springs that form naturally from impermeable blue clay outcrops in perched aquifer systems rise to more frequent flows in the connected reaches of the watercourses.

This spatiotemporal variability in flow creates an assortment of dry, lentic and lotic patches along the valley bed that govern nutrient and organic matter processing (Larned et al., 2010). Biotic communities form into a mosaic of aquatic, semi-aquatic and terrestrial habitats. These dynamics are further complicated by human influences. Following thousands of years of colonisation, the landscape of the Maltese Islands has been subjected to intense modification. Valleys have been transformed to accommodate agricultural land and urban conurbations. Hydrological functioning has been altered through the modification of bank structures and construction of small dams and weirs for irrigation purposes. Water quality has been degraded by discharges of chemical contaminants, mostly originating from industrial sources and, nutrient-enrichment resulting from agricultural activities (SEWCU & ERA, 2016). Invasion of freshwater biodiversity by alien species has also contributed to the displacement of indigenous flora and fauna (e.g., Deidun et al., 2018). These dynamics make the management of valleys complex, particularly as the drivers to be managed are often beyond control.

The decades of neglect and misuse of valleys irreversibly compromised the water-carrying and absorption capacity of Malta's valleys and combined with dense urbanisation from repeated building booms, the geomorphology and hydrology of the lower parts of most catchments was altered radically. Consequently, the inadequacy or absence of storm water infrastructure was resulting in the accumulation of uncontrolled surface water runoff in urbanised areas of the valley channels (Sciberras et al, 2017). Quick-fix remedies involving the bulldozing of valley beds were not uncommon as part of the valley clean-ups, undertaken in the 1980s and 1990s, which are aimed to alleviate the problems of inundation of populated areas with flood waters by cleaning valley beds to increase flows.

In the last few decades there was an increasing recognition that such traditional piecemeal approaches to solving flooding problems locally were ineffective as they were either shifting problems or creating new ones downstream, while they achieved very little in terms of water conservation. More recently, Malta has experienced the advent of an IEM approach to the management of valleys in the last few years or so. Within this span, the focus has shifted from a dominant concern for mitigating the risks of flash flooding in high-investment and densely populated areas, to one for greater water conservation. This shift occurred as risks to life and property were mitigated in the most notorious areas through major infrastructural works of the National Flood Relief Project, completed in 2015.

Cognitive Challenges to IVM in Rainwater Harvesting

At present, attaining cognitive integration of the substantive data and information required for the integrated management of valleys is still a challenging task. This is due to the ephemeral nature of the surface waters. The importance of understanding their dynamic is undeniable: They replenish valleys with their life-supporting qualities, provide ecological services in the form of fresh water supply, while also, at times, this resource turns into a hazard as it creates life-threatening flooding events that also cause unprecedented risk to property in whole areas of high investment.

The management of valleys is complex, involving social, economic, and environmental dimensions (Kingsford et al., 2017). To appreciate the complexity, it is useful to consider the view that: 'neither the environment nor parts of it are resources until they are, or are, capable of satisfying human needs' (Mitchell, 1989:1). Environmental 'values' are an expression of appraisal, depending on their benefit or cost to society. A resource can easily become a hazard, and also involve different dimensions of a problem with often competing interests. But the issue of attaining a thorough understanding and good level of knowledge integration about the dynamics of valley hydrology is critical for their strategic management.

Different sectors from society necessitate differing ecosystem services from valleys including water for irrigation; recreational activities that vary from hiking and picnicking to hunting and off-roading and other cultural and religious-related purposes, amongst others. The piecemeal management of valley sections may limit the attainment of desired targets such as the eradication or control of invasive and/or non-native species or preserving endangered populations, because different stream components interact through time and space in complex ways (Leigh et al., 2016). Valley catchment processes often occur over long distances and hydrological connectivity within valleys can be explained as being three-dimensional: longitudinal, lateral and vertical. Longitudinal connectivity is driven by gravity and results in longitudinal trends in geomorphology, water flow, water chemistry, and ecology (Boulton et al., 2017). The spatial extent, flow rates, and residence time of surface water spreading laterally across different catchments are strongly driven by the topography, substrate composition, and vegetation cover as these govern runoff and rates of evapotranspiration and infiltration (Hamilton, 2010). Finally, vertical connectivity refers to evaporation, direct rainfall and exchange between the surface and the underlying aquifers (Boulton et al., 2017).

Bridging the Gaps in IVM

A good understanding of these processes acting at different (longitudinal, lateral and vertical) spatiotemporal scales is essential for the management of valleys. Due to its spatial coverage, potential for high temporal repeat rates and ability to access previously unreachable locations, remote sensing has increasingly been used to map and monitor river environments (e.g., Marcus and Fonstad, 2010; Carbonneau et al., 2012). Remote sensing offers an efficient approach to cover extensive areas with spatially continuous coverage of fluvial systems (Tamminga et al., 2015; Woodget et al., 2015), which cannot be achieved by traditional means.

Since the launching of Landsat 1 in 1972 remote sensing technology has played an increasingly significant role in detecting, mapping, understanding, and predicting changes and patterns in the environment (Rose et al., 2014). Remotely sensed data provide effective solutions for catchment-scale studies in large rivers and floodplains but are unsuitable for small intermittent and ephemeral streams as those found in the Maltese Islands. Table 2 lists the satellite data available for Malta. High resolution images ranging from <1m to 5m are available but their repeat cycle ranges between every 5.5 and 26 days which may not be sufficient to study ephemeral streams that only flow for a limit period of time, usually for a few days following a rainfall event. Furthermore, these images are available only against high fees that may too exorbitant, especially when used for research purposes. Alternatively, both the European Commission and the National Aeronautics and Space Administration (NASA) are offering satellite images and datasets at no costs, almost on a daily basis, but these are not satisfactory in terms of resolution to map and study valley systems.

Table 2: Availability of Satellite Data for Malta

Satellite	Resolution	Repeat for one (1) Cycle	Source
Spot 6/7	1.5m	26 days	https://earth.esa.int/web/eoportal/satellite-missions/s/spot-6-7
Pleiades	<1m	26 days	https://www.satimagingcorp.com/satellite-sensors/pleiades-1/
COSMO-SkyMed	5m	16 days	https://eoportal.org/web/eoportal/satellite-missions/c-missions/cosmo-skymed
Rapid Eye	5m	5.5 days	https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/rapideye/
Sentinel 2	10m	5 days	https://sentinel.esa.int/web/sentinel/missions/sentinel-2

Although techniques such as sub pixel classification of high-resolution satellite imagery are being increasingly developed for integrating very high spatial resolution multispectral remote sensing with updated algorithms to map transient stream networks (Costigan et al., 2017; Niroumand-Jadidi and Vitti, 2017), imagery using unmanned aerial vehicles (UAVs) such as drones, are more practical in smaller streams. A growing body of literature demonstrates the use of UAVs alongside structure-from-motion (SfM) digital photogrammetric image processing as an alternative approach for the remote sensing of rivers at very high resolutions. SfM applications allow the reconstruction of real-world images in 3D without prior knowledge of camera positions or the use of ground control points (Woodget et al., 2017). Numerous commercial software packages have adopted the SfM-photogrammetry method and the processes involved are usually automated and can be performed easily by non-experts (Woodget et al., 2017).

The combination of these techniques is particularly suited to valleys in the Maltese Islands, where the ability to swiftly respond to wetting and drying events is vital for appropriate management. These tools have the potential to allow for the better understanding of the influence of hydrological intermittency on other stream biophysical variables at greater resolutions and more frequent intervals (Politi et al., 2016). The current revolution in UAV technology has also considerable implications for the improved monitoring and management of valleys systems. For example, satellite imagery is not sufficient for the detection of single plants/vegetation strands that can lead to the re-establishment of the plant in the mapping of invasive vegetation for eradication and control measures (Samiappan et al., 2017). In addition, the revisit rates of satellites further limit the accessibility of near real-time data that can affect management efforts as the invasive plants may have spread beyond the last known border of a specimen (Samiappan et al., 2017).

Transferability and Applicability to ICM and IVM in Malta

The cognitive barriers to an effective IEM approach for (i) managing risks from coastal erosion and, (ii) safeguarding the environmental values of ephemeral streams, are similar in the spatiotemporal sense. However, the key variables that need to be monitored and the processes that require a more comprehensive understanding in either case, vary, and thus the most appropriate set of tools and techniques required in each case, needs to be selected accordingly.

Furthermore, even within each of the two realms discussed here, the use of tools and techniques adopted in other countries has to be evaluated further with regard to their transferability and applicability to the Maltese context. The aim of this final section is to discuss the suite of remote sensing techniques discussed earlier, in this context, with a view towards providing a heuristic set of parameters to be considered for their local application.

These can be considered in matrix form on account of (i) the general requirement for measurement and investigation which needs to be addressed against (ii) the wider terrain, spatiotemporal and accuracy/quality trade-offs with available resources.

General Requirements for Measurement and Investigation

In the case of monitoring land movements and deformation, for coastal hazard management, the range of situations monitored vary in terrain, climatic and geological conditions, but the key processes for which to watch out for remain common across from the alpine regions to the Mediterranean coasts. Nonetheless, one shoe does not fit all, whereby planning the data acquisition campaign and selecting the best-suited monitoring techniques requires consideration not only of the local geological conditions to be monitored, but also other contextual factors, which are explored in this section. Four risk-producing elements of wider processes (rockfall, landslide, debris-flow, and deformation) were proposed earlier as a conceptual reference framework to help to identify and locate the origin, or exacerbation of risk, by a series of preconditioning and triggering factors, nested in the wider process-oriented view. These constructs are aimed to provide a better understanding of the natural processes in the real world, on one hand.

On the other hand, the notion of management with the use of data acquisition for the virtual: characterisation, mapping, modelling and monitoring of such stages and occurrences in the processes, and interaction of preconditioning and triggering factors, is a conceptual and virtual tool used to represent reality so that processes can eventually be foreseen and management decisions taken accordingly, to mitigate or cope with the foreseen risks and hazards, or other resource issues. The question being followed up is which remote sensing techniques are most suited for given situations, and on what basis can the selection of different techniques by planned and selected to best suit management needs in practice.

It is now proposed that the conceptual constructs of what is happening in the real world need to be considered in the ambit of the virtual management needs for investigation and measurement (characterisation, mapping, modelling, monitoring and prediction), to provide a guide to noting the level of accuracy required for consistent monitoring, and hence the type, and combination of techniques that are appropriate, for the given situation. The management needs and requirements for accurate measurement and investigation is driven by different types of management needs encountered locally are typical of all the four types identified by Jaboyedoff et al (2012) – noted as attainable using remote sensing, TLS and ALS, in particular: (1) Landslide (and rock fall) detection and characterization; (2) Hazard assessment and susceptibility mapping; (3) Modelling; (4) Monitoring.

The three remote sensing methods, most used to observe such changes in topography and geomorphology in unforested areas for rockfall and landslide hazards are digital airborne photogrammetry (DAP) and more recently, terrestrial- (TLS) and airborne laser scanning (ALS) (Kenner et al, 2014). In the case of valley management, the modelling of topography and hydrology at the wider spatial scale is important for deriving flows. A more refined measurement of changes in terrain at specific areas, with temporal capture, is then required for recording erosional changes, material transportation and sedimentation, caused by the flow of water in combination with geomorphology and man-made structures, such as dams.

In combination with rainfall data, and site-specific information of the local geology, when understood collectively, these datasets provide meaningful information that builds knowledge about the available retention volumes of valley basins and artificial retentions, as well as about rates of percolation and the potential for aquifer recharge. Modelling of the overall hydrological performance has major benefits for both flood relief and water conservation. Following the same logic as for rock hazard areas, it can be deduced (at a general level, of course) that four important types of requirements for measurement and investigation need to be addressed locally in valley management. These are also attainable using remote sensing: (1) Flow detection and characterisation; (2) Mapping of flood hazard or water conservation potential; (3) Modelling; (4) Monitoring.

Specific Terrain, Spatiotemporal Conditions, Needs and Resources

All three measurement methods (DAP, ALS, and TLS) have specific advantages and disadvantages, for different measurement and investigation needs in each realm. The selection of the most appropriate techniques is highly dependent on the conditions at the measurement site and on the aim and specific management objectives of data capture, as well as its temporal and spatial requirements (regular or one-off; extensive or limited site). Three groups of factors can be considered successively, side by side with the generic types of management needs, as a set of layered parameters than can guide the planning and selection of the most appropriate suite of remote sensing techniques for a given situation:

Inherent Characteristics of the Terrain:

Vegetation cover is one consideration. Locally, coastal areas are mainly barren, with most surfaces being exposed and of a good reflective quality, lending themselves suitable for most LiDAR. Areas where vegetation is prolific and dense may be problematic and a combination with more point-based and locally focused methods may be required to cover such areas. Locally, valleys are more likely to merit such an approach for this reason. Topography is another factor. This can be problematic if it is characterised by pockets and projections that are difficult to scan by area-based (and especially satellite) methods and would again require a combination of methods. On the other hand, topography could provide good vantage points with direct frontal views, as in steep valleys and coastal inlets, making then ideal for TLS, which can compensate for steep slopes that are captured poorly by satellite imagery.

Accessibility and availability of artificial targets, GCPs or GPS reference points is also important when planning a monitoring campaign. Meanwhile, the use of UAVs, depending on their availability, may prove to be the most adept for data acquisition over pocketed areas or relatively inaccessible terrain aspects and orientations.

Spatiotemporal Requirements for Data Acquisition

Spatial and temporal requirement for the acquisition of data will have a bearing on the selection of the most appropriate remote sensing techniques. The specific requirements of the monitoring campaign need to be well defined and curtailed to meet the expected level of knowledge for making management decisions. Building a sound knowledge base and a comprehensive understanding of the processes at play is a pivotal starting point. Planning data acquisition to achieve this requires clarity and focus on the profile of data that needs to be captured, in terms of quality, frequency and timing, as well as geographic extent, and attributes. This needs to be planned for ahead to make the assimilated data, comprehensible, to turn it into meaningful information that can be regarded as useful knowledge:

- At the spatial level, the scale and intensity of data required needs to be defined, and hence the appropriate techniques for such acquisitions, and,
- At the temporal level, the frequency, overall duration as well as the timing of specific acquisition must be envisaged and planned, bearing in mind the most appropriate techniques to meet these specific needs, for the given terrain characteristics.

Accuracy, Quality and Resource Tradeoffs

Accuracy requirements and quality of monitoring are often a trade-off against cost, time and other resources. The specific aims of monitoring and the processes to be monitored dictate the level of accuracy required but selection of techniques is not a straightforward choice. It requires verification of results and validation of the methods being used for the site, prior to undertaking long-term investigative and monitoring campaigns.

For instance, TLS has been claimed to be one of the most accurate measurement methods, even to millimetric scale in some instances (also depending on the instrument – and its outlay and operational costs). But depending on the object being studied one question that remains to be resolved is whether the instrumental error of TLS systems is small enough to detect pre-failure deformation on rock slope surfaces in the Maltese context where deformations due to erosion or landslides are spatially of a millimetric scale, commonly recorded over years and decades. Depending on the methods and instrument, as well as conditions, errors may mask the very changes that a monitoring campaign may set out to measure and record.

Selection Parameters

To facilitate the selection of appropriate remote sensing techniques for the particular situations of coastal and valley management discussed here, these groups of factors are being proposed hereunder as a heuristic set of parameters that can be taken into account sequentially to sharpen the main management needs for a clearer vision of the techniques that can be employed to address them. The matrix is aimed at providing key considerations that could enable a better selection, with transferability and application of the appropriate mix of remote sensing techniques in the respective local context:

On a concluding note, the consideration of remote sensing as an unprecedented management tool is most timely in the local scenario, not only for ICM or IVM, but also more widely. This point in time may be seen as indeed one of the most opportune, as a range of instruments are being acquired for use across public entities under the SIntegraM project. The availability of such instrumentation, if capitalised, can induce a shift towards more complete and refined data acquisition that can bridge cognitive gaps in different policy areas across the country. The above discussion of specific needs and peculiarities of ICM and IVM, reveals challenges that can be tackled with the use of techniques that could be employed through the use of newly acquired equipment that include vehicles, underwater drones, AUVs and terrestrial-based scanners and instruments, hosting a range of cameras, laser scanners and other data acquisition equipment.

In this sense, it is being recommended that, for instance to start with these two realms, an overall analysis of the geographic location of situations and specific management needs, is carried out, to identify specific needs and cognitive challenges that can be tackled through remote sensing techniques that could be employed through the equipment that will be available shortly through SIntegraM. This can be achieved by evaluating matters against the above set of heuristic parameters (within the wider background provided by the earlier sections, for ICM and IVM, in particular, and likewise in other areas). This can be developed as a strategy that identifies cognitive gaps that are barring management needs from being met, and then to provide a multi-technique and inter-disciplinary plan for data acquisition to address the specific management objectives. This is not an end but needs to be taken as the starting point from which the strategic plan for data acquisition and monitoring, using different techniques, can be coordinated and implemented through the use of available technology and collated spatial datasets, integrated nationally. It would be invaluable for the purpose of guiding initiatives that can build a more comprehensive understanding of the processes at play. Each realm requires its own strategy in this regard, and therein, different areas will warrant selection and applicability for different remote sensing techniques, to address specific needs in each situation.

The foregoing discussion amply demonstrates that it is not as much a question of whether or not knowledge, information and data gaps can be bridged, but more a question of how to approach and bridge these gaps – which is the view adopted by this chapter in attempting to provide some insights for approaching the latter question through the heuristic set of parameters presented in matrix form, and in putting forward the above proposals for advancements in data acquisition an improved cognitive integration in environmental management.

Table 3: Heuristic Matrix for Step-by-Step Considerations for Selection

<table>
<tr><td></td><td colspan="2">FIRST: Focus the Objectives and Management Needs for Quantitative Measurement and Investigation</td><td colspan="3">THEN, consider the other conditions and needs in terms of the layered groups of specific factors and questions below
> ></td></tr>
<tr><td></td><td>ICM</td><td>IVM</td><td>Terrain Characteristics</td><td>Spatial temporal</td><td>Accuracy and Resources</td></tr>
<tr><td>1</td><td>Landslide (and rock fall) detection and character-isation</td><td>Flow detection and character-isation</td><td rowspan="4">Consider features:
• Access to vantage points
• Access to reference points (GCPs)
• Distance to target objects
• Lines of Visibility
• Obscuring objects</td><td rowspan="4">Identify Capture Requirements:
• Geographic extents
• Required scale
• Buffer areas
• Frequency (how often)
• Timing (when)
Duration (overall period)</td><td rowspan="4">Decision on Trade-offs:
• Time Limits
• Budget
• Adequacy for Management Need to be met:
• Accuracy and Reliability</td></tr>
<tr><td>2</td><td>Hazard assessment and susceptibility mapping</td><td>Mapping of flood hazard or water conservation potential</td></tr>
<tr><td>3</td><td>Modelling</td><td>Modelling</td></tr>
<tr><td>4</td><td>Monitoring</td><td>Monitoring</td></tr>
</table>

Conclusions

Effective management of local risks to safety from coastal erosion and, conservation of the transient water valley resources, still lacks a more comprehensive and integrated understanding of the environmental processes taking place in each area. Remote sensing and associated techniques offer a wide range of applications that can be employed with different targets in mind. The specific knowledge gaps being encountered locally arise from the inaccessibility to information, given the transient or unsafe environments about which data needs to be collected, regularly, extensively, and to a good level of accuracy. However, these challenges have also been encountered elsewhere, and are being overcome with the use of appropriate remote sensing techniques.

The foregoing sections demonstrate how parallels can be drawn across the cognitive challenges that are being encountered in Malta due to spatiotemporal needs for data capture. It is clear that remote sensing techniques are an inestimable support not only for (i) rockfall, landslides, debris flows and land deformation in coastal areas, and (ii) flow detection and characterisation in temporary streams, but also for the assessment and monitoring of hazard and resource potential in these areas. At the local level, there is a strong case for improving or introducing campaigns for measurement and investigation of key elements for a better understanding of the processes and dynamics at play, for both ICM and IVM. Each area requires an appropriate set of techniques to capture meaningful data for the respective environmental management objectives, but a common challenge faced in the two realms is a cognitive one, created by the inherent nature of the resources being managed.

Present indications are that research does not yet well-define the limitations of LiDAR, as the number of applications, and their combined use, continues to unfold incessantly. The use of the full data quality for modelling purposes is still not achieved. Following the current trend, full coverage by ALS-DEM in most of the rich countries will be reached within the next 10 years. As techniques are also progressing, more accurate and precise ALS and TLS devices will appear, allowing for the generation of more accurate DEMs.

Furthermore, the two major remote sensing techniques of TLS and ALS are exponentially developing in combination with inferometry in different fields. The techniques of interferometry provide a wealth of information about the profile of an object under test and its material characteristics; its fringes, like lines on a topographic map, represent the topography of the object. Techniques have been developed to retrieve a wide range of information from the object under test.

The real challenge is to develop new methods to better take benefit from HRDEM. Indeed, new information can be extracted from such DEM. At present and in the near future, environmental pressures and the need for more complete integration of knowledge will contrive us to enhance our capture of such data and to use it more effectively. This will require, first and foremost, discernment of the cognitive challenges that are impeding an IEM approach at the cognitive substantive level in each of the four identified types of management needs for more precise quantitative measurement and investigation in both ICM and IVM.

A vantage point for selecting appropriate remote sensing techniques requires (1) the wider appreciation of what has been done, and what can be done elsewhere, as discussed in the spectral view of remote sensing techniques that were only overviewed in the first section, together with (2) consideration of the specific requirements and conditions of the given situations of local ICM and IVM, dealt with separately in the Maltese context, in the two sections that followed. Altogether these steps provide a springing point for bridging the gaps in the presently unsatisfactory situation of incomplete knowledge, with better data capture that helps us build meaningful information to bridge over these cognitive gaps. It is hoped that the parameters brought to mind in the last section can provide guidance to the selection, utilisation and wider applicability of remote sensing techniques that are most to these ends in the local context.

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CHAPTER 5

Copernicus Sentinel-2 imagery for land cover assessment of the Maltese Islands

Elaine Sciberras

Introduction

Copernicus is a flagship space programme of the European Union (EU). The Copernicus programme monitors the Earth and its ecosystems and provides the necessary information to prepare and protect in the case of natural and man-made disasters. Copernicus is served by a set of dedicated satellites called Sentinel satellites, as well as contributing missions using existing commercial and public satellites. Copernicus also collects information from *in-situ* systems such as ground stations, which deliver data acquired by a multitude of sensors on the ground, at sea or in the air. Based on satellite and *in-situ* observations, the Copernicus services deliver near-real-time data on a global level which can also be used for local and regional needs, to help us better understand our planet and sustainably manage the environment we live in (EU, 2018). The Copernicus programme also offer services which transform this wealth of satellite and *in-situ* data into value-added information by processing and analysing the data. These pertain to **six thematic streams of Copernicus services**: atmosphere (CAMS), marine (CMEMS), land (CLMS), climate (C3S), emergency (EMS) and security.

The Copernicus programme derives its success from various factors:

1. Copernicus is a user driven programme that has been specifically designed to meet user requirements;
2. Full, free and open access to Copernicus data, products and information (both Sentinel data and service products);
3. European strategic cooperation in space research and industrial development and the delegation of the programme's service and space components to competent entities under the direct responsibility of the European Commission. (Copernicus Committee, 2018)

Through the Copernicus Services, the Copernicus programme offers full, free and open access to data, models and forecasts related to the monitoring of our environment. It also makes satellite data from the Sentinel constellation available on a free full and open basis (Copernicus Observer, 2017).

BACKGROUND

Sentinel-2A for deriving land cover information

The Copernicus Sentinel-2 mission comprises a constellation of two polar-orbiting satellites (Sentinel-2A and Sentinel-2B) placed in the same orbit, phased at 180° to each other. Sentinel-2 satellites aim at monitoring variability in land surface conditions. The first satellite, Sentinel-2A, was launched on 23 June 2015 whilst Sentinel-2B was launched on 7 March 2017. To achieve frequent revisits and high mission availability, these two identical Sentinel-2 satellites are planned to operate simultaneously (ESA, 2018). Their wide swath width allows a high revisit time, of about 5 days with 2 satellites under cloud-free conditions in the Maltese Islands latitudes. Sentinel-2 satellites provide multi-spectral data with 13 bands in the visible, near infrared and short-wave infrared. Sentinel-2A satellite is the first civil optical Earth observation mission of its kind to include three bands in the 'red edge' at a 20m spatial resolution, which provide key information on the vegetation state (ESA[1], 2018). Four of its bands (B2-Blue, B3-Green, B4-Red and B8-Near Infrared) are available at the highest resolution of 10m for the range of available bands. Hence, due to their high-resolution, these bands are of practical use to investigate land areas where higher resolutions are required. The high revisit time provides the potential for up-to-date, medium-to-high scale land cover products.

Several documented studies use Sentinel data for land cover classification with differing classification methodologies and thematic classes. Since the launch of Sentinel-2 satellite, technical studies on the use of Sentinel-2 imagery for various terrestrial applications are set to increase. Clerici *et al.* (2017) used a combination of Sentinel-1 and Sentinel-2 imagery to take advantage of the fusion of radar and optical data for land cover mapping and increased mapping accuracy. Radar data allows terrain analysis in areas with frequent dense cloud cover. The study area covered about 2095 km^2 in the Lower Magdalena region of central Colombia.

Visual inspection of the object-oriented classification methods used versus a national colour composite of Sentinel-2A imagery was applied together with thematic classification accuracy indices. In the classification accuracy assessment, Clerici *et al.* (2017) noted that omission and commission classification errors were found in crops and secondary vegetation/shrubs due to the high spectral heterogeneity present in both classes to the variety of crops and vegetation types/growth stages. Lefebvre *et al.* (2016) used both Landsat and Sentinel-2 imagery to monitor urban areas in Prague and Rennes and to update Copernicus Land services, particularly the High-Resolution Layer imperviousness. In addition to all spectral bands, a texture index was added as feature descriptor to accurately represent urban areas. Drusch *et al.* (2012) highlights the contribution Sentinel-2 imagery towards Land Monitoring, Emergency Response and Security services. The respective user requirements for these services have driven the design towards a dependable multi-spectral Earth-observation system featuring the Multi Spectral Instrument (MSI) with 13 spectral bands, spanning from the visible and the near infrared to the short wave infrared.

Reporting of land cover: the EU and local dimensions

The EU has invested significant funds in its EU Space Programme which include the Earth Observation (EO) – Copernicus programme (EC, 2018). The use and advantages of Copernicus programme through the range of services it offers is included in the "Space Strategy for Europe" (COM (2016) 705), published on 26 October 2016 (EC, 2016). At a local level, the recognition and importance of the use of satellite imagery for Earth Observation is formalised in the Malta National Space Policy (MCST, 2017) published in 2017. This policy highlights the use of satellite imagery for spatial planning analysis as a data source to provide information, particularly when substantiated by high resolution datasets such as those derived from aerial orthophotos, LIDAR (Light Detection and Ranging) and Unmanned Aerial Vehicles (UAVs).

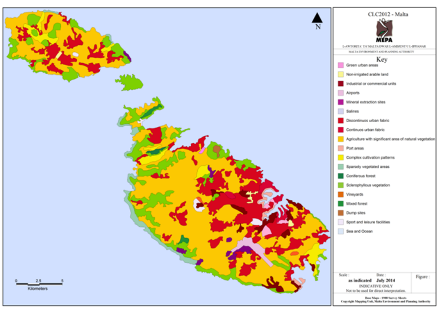
As part of its reporting obligations on land cover to the European Environment Agency (EEA), the Planning Authority (PA) in Malta is responsible to produce outputs for the Maltese Islands as part of the CORINE Land Cover Change (CLC) program. The CLC consists of an inventory of land cover in 44 classes and forms part of the Copernicus Land Monitoring Service. National Reference Centres Land Cover (NRC/LC) produce the national CLC databases, which are coordinated and integrated by EEA. The 2012 version of CLC is the first one embedding the CLC time series in the Copernicus programme, thus ensuring sustainable funding for the future (Copernicus Programme, 2018). Medium and high-resolution satellite imagery are used to derive the required maps for the Maltese Islands including the use of aerial orthophotos for image interpretation purposes. The CLC information assists with understanding land cover and monitoring large-scale changes over longer timeframes. In the case of the Maltese Islands, the large scale (25 ha) of the grid used does not permit analysis that is sensitive enough to monitor short-term land-use change in with a great deal of accuracy. Snapshots of Malta's land cover in as part of CLC reporting for 2012 and 2018 are shown in Figure 1. Satellite data for 2012 imagery was derived from Pleiades, SPOT-6 and SPOT-7 whereas Sentinel-2 was used to derive 2018 imagery.

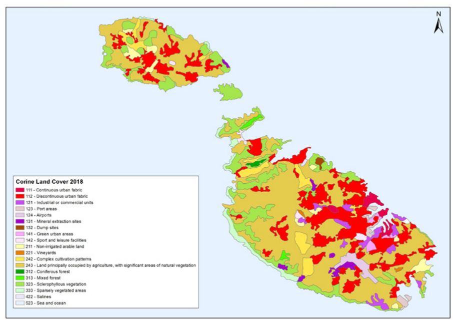
The Planning Authority has regularly produced reports and maps on the terrain of spatial planning relevance, such as the designation of Areas of High Landscape Value

(AHLV), as part of its 1990 Structure Plan for the Maltese Islands. The latter was superseded by the Strategic Plan for the Environment and Development (SPED) which is based on an integrated planning system that regulates the sustainable use and management of land and sea resources (PA, 2018). Satellite data are not used to produce any these maps with the latter being based on visual inference from aerial orthophotos and knowledge of the terrain. Therefore, the free and open use of satellite data from the Copernicus programme provides a motive to use Sentinel data for various applications, including that to derive land cover from Sentinel-2 imagery. Furthermore, the availability of high resolution aerial orthophotos produced by the Planning Authority are key data to aid in the interpretation of medium resolution Sentinel-2 data.

Figure 1: (a) CLC2012 and (b) CLC2018

(a) *(b)*





Sources: (a) EEA and (b) PA

Sentinel Data Access

Sentinel satellite data are distributed by the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). Access mechanisms to the Sentinel data are tailored to the purpose they will be used for. Both ESA and EUMETSAT operate data access 'hubs' for on-demand, open access to Sentinel data (Copernicus Observer, 2017). Both Sentinel satellite data and Copernicus service data and information can be accessed freely through dedicated access portals and which require a dedicated login.

Operational Sentinel satellites (Sentinel-1A and 1B, Sentinel-2A, and Sentinel-3A) will deliver in excess of 10 petabytes of data each year (Copernicus Observer, 2017) and this is set to increase with the operation of future suites of Sentinel satellites, such as the

Sentinel-5P launched in October 2017 and the future Sentinel-4 satellites. Information from the Copernicus services, derived from the Sentinels, other satellite data, as well as information from the Copernicus *in-situ* component, add to the total amount of geospatial data generated or made available by the Copernicus programme. This makes Copernicus the third largest data provider in the world. Consequently, the European Commission launched the Copernicus DIAS – Data and Information Access Services. The DIAS will create the development of a European data access and cloud processing service, open for entrepreneurs, developers and the general public to build and exploit their Copernicus-based services (Copernicus Observer, 2017).

Prior to DIAS, some commercial initiatives did emerge and offer the processing of some Sentinel satellite data in the cloud. One of these is the Copernicus Research and User Support (RUS) Service portal. The RUS Service is a free-of-charge service funded by the European Commission. It offers a scalable cloud environment to remotely store and process Earth Observation (EO) data (Copernicus Observer, 2018). Its powerful ICT platforms allow processing of EO and GIS data and provides a dedicated helpdesk for assistance, a chat service, a discussion forum and the organisation of regular training webinars (RUS, 2017). The RUS training portal allows EO users to better understand and investigate the various applications of EO to studying Earth processes such as flood aping, urban area mapping, fire mapping and ocean colour.

The DIAS approach emanated from the European Commission's identification for a widely shared need to access the Copernicus data and information close to processing facilities to allow further value extraction from the data. As this need is shared across Europe and, in order to avoid duplication of data storage activities across Europe, the European Commission will provide a dedicated service approach that is complementary to the traditional data download. This service approach, the DIAS, will offer access to Copernicus data and information close to processing facilities and, through this, create the possibility to easily build applications and offer added-value services. Whilst the DIAS service will give unlimited, free and complete access to Copernicus data and information, tools and services will be offered to the users through scalable computing and storage resources at competitive commercial conditions (Copernicus Observer, 2017). Therefore, DIAS offer users the capability to exploit Copernicus data and information without having to manage transfer and storage on their own computer systems. DIAS was officially launched on the 21$^{st of}$ June 2018 in Baveno (Italy) during the celebration of the 20th anniversary of the European Union's Earth Observation programme Copernicus. In order to foster the competition and the development of creative solutions, the EC has awarded five different DIAS providers, operated by different commercial consortia.

Methodology

This study involved a multitemporal and multispectral analysis to investigate land cover changes over the Maltese Islands. The first step involved the selection of recent cloud-free Sentinel-2 images from two varying seasons. The latter would consider variations in vegetation and crop coverage, particularly due to the dry summer season.

Image selection and download

The Copernicus Open Access Hub was used to search Sentinel-2 imagery to allow free and open download of the requested imagery. Selection criteria included sensing period, ingestion period, satellite platform, product type and percentage cloud cover. Two Sentinel-2A images were selected pertaining to 6th August 2017 acquired at 09:50 CET and 25th October 2017 acquired at 09:51 CET. Both images were downloaded at processing Level-2Ap (Figure 2).

Figure 2: Sentinel-2A image downloads for (a) 06/08/2017and (b) 25/10/2017 using Natural Colour band combinations

(a) *(b)*

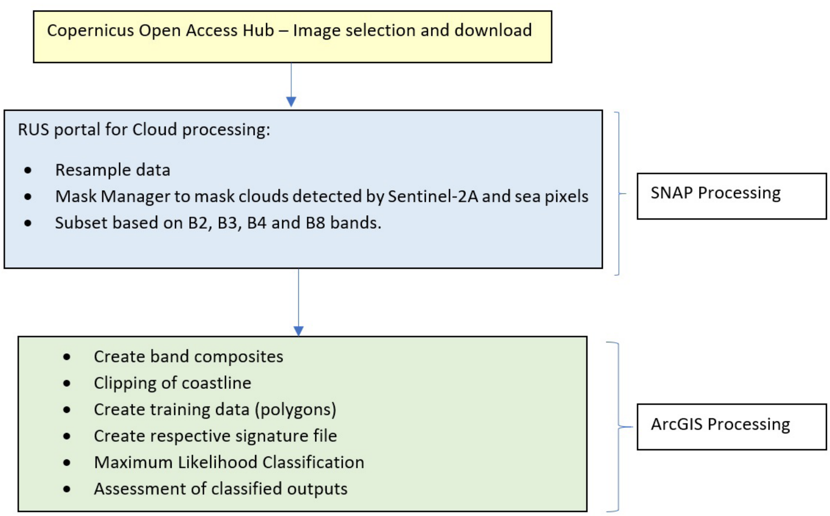
Source: ©European Space Agency

Image processing

Pre-processing of both satellite images was carried out through cloud processing using the Copernicus Research and User Support (RUS). The Sentinel Application Platform - SNAP Desktop - software developed by the European Space Agency (ESA) was used. SNAP is a freely downloadable software dedicated to processing of Sentinel data. An overview of the pre-processing steps carried out in SNAP is given in Figure 3.

The cloud masks available from the respective S2A image downloads enable cloudy and cloud-free pixels to be identified. The mask includes both dense clouds and cirrus clouds with an indicator specifying the cloud type. The dense clouds, also called opaque clouds, are characterised by a high reflectance in the blue spectral region (B2). Cirrus clouds are thin, transparent, or semi-transparent clouds. Cirrus cloud pixels are identified based on B2 and B10 spectral criteria (ESA[2], 2018). Pixels labelled as water, and identified as being those over the sea areas, were also included in the mask so as to create a combined Cloud Sea mask. The exclusion of sea areas was further carried out using a common coastline feature class that was implemented on both satellite images through a clip function from ArcGIS software. In order to reduce file size of the two temporal images noted in Figure 2, images were subset to include the terrain area as well as only the bands for which image classification would be required: specifically B2, B3, B4 and B8 spectral bands.

Figure 3: Methodological processes performed in this study



Given the medium resolution of the Sentinel-2A imagery of 10 m, high resolution aerial orthophotos were used to aid in the creation of training samples from the satellite imagery. In this case, the PA's aerial orthophotos acquired in 2016 with a spatial resolution of 15 cm were used. 114 training polygons were designated over the Area of Interest that incorporated the following training classes (Table 1):

Table 1 – Preliminary training classes used over Area of Interest prior for the first run of MLC

Class
Vegetation – non-arable
Vegetation Arable
Rock face (valley)
Urban
Sea
Sandy beach
Man-made water body
Inland water body
Bare surface (impervious)
Bare surface - quarry
Bare surface - coast

Subsequently, signature files were created for these training classes. Maximum Likelihood Classification (MLC) was carried out on two combination composites for each date: Composite 1 B2, B3, B4, and Composite 1 B2, B3, B8. The aim was to note the varying effect of the Red and NIR bands on the classification of vegetated areas. Resultant MLC outputs were analysed using both visual interpretation and Extract by Mask for a qualitative accuracy assessment.

Results

Analysis of MLC outputs

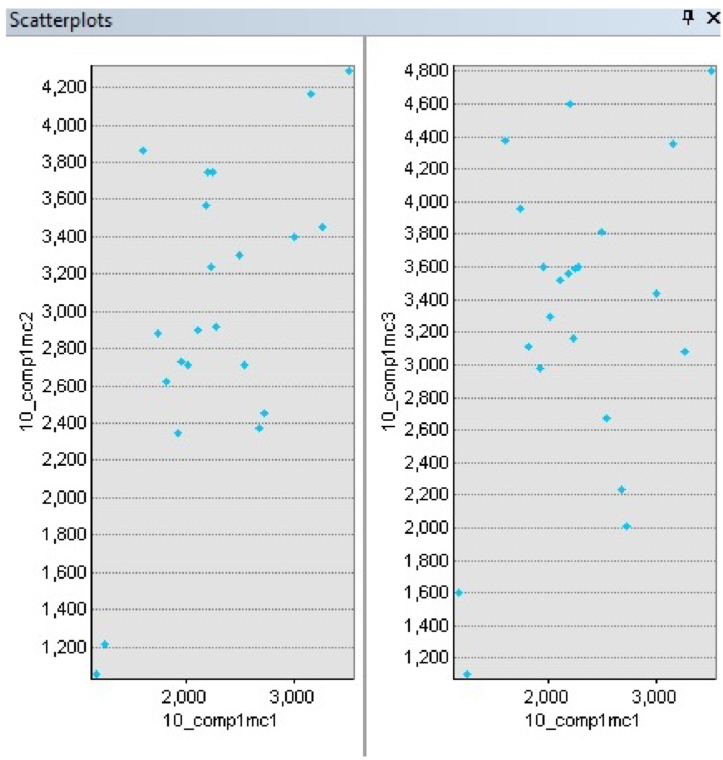
Following visual interpretation of the resultant MLC images, as well as interpretation with respect to the aerial orthophotos and class scatterplots, it was decided to merge classes with overlapping spectral signatures. This occurred in the case of the three classes, *Bare surface (impervious)*, *Bare surface – quarry* and *Bare surface - coast*. In the case of the *Sandy beach* class, the spectral signature conflicted with those of other coastal areas due to the varying sand colour of the various locations of these sandy beaches. The *Man-made water body* class incorporating features such as swimming pools did not exhibit a distinct spectral class (Figure 4a), most likely due to their relatively small area with respect to the 10 m resolution of the satellite pixels, and the spectral heterogeneity from mixed pixels. In fact, in the August image, the *Impervious surfaces* class was also noted to include swimming pool areas. In the October image, pixels over areas covering valleys, their shadows and main roads were seen as dark pixels in the Composite 1 image and were grouped into one class. Consequently, the training classes were updated (Table 2) for which the final run of MLC was carried out with the respective clustered spectral signatures indicated in Figure 4b.

Table 2: Merged training classes used over Area of Interest prior for the final run of MLCfor 06/08/2017and 25/10/2017 images

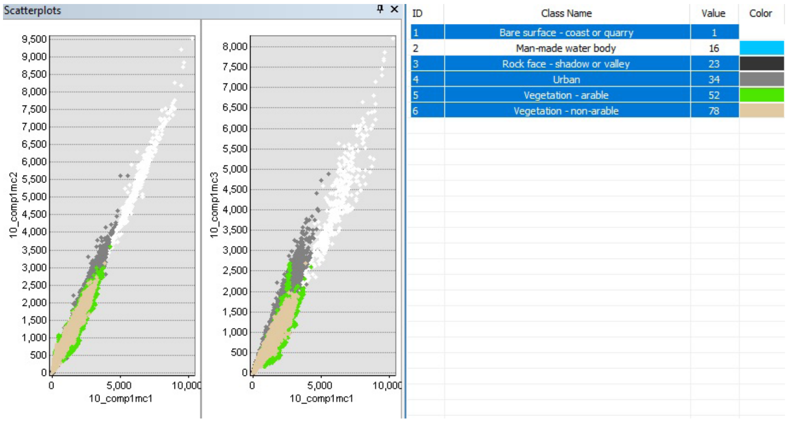
Classes (*06/08/2017 image)*	**Classes** *(25/10/2017 image)*
Vegetation – Non-arable	Vegetation – Non-arable
Vegetation Arable	Vegetation Arable
Valleys, shadows or roads	Valleys, shadows, or roads
Urban	Urban
Bare surface inc. coast or quarry	Bare surface inc.coast or quarry
Impervious surfaces	

Figure 4: Spectral signature scatterplots for training samples for (a) man-made water body class; (b) updated training classes used for final MLC outputs

(a)



(b)



The class '*Vegetation*' denotes vegetated areas that are non-arable, including sclerophyllous coastal areas. From the analysis of the resultant MLC maps, it was noted that the best composites for both dates pertained to Composite 1 - B2, B3, B4. Visual interpretation MLC maps derived from Composite 2 indicated that the use of B8 misclassified a large expanse of the vegetation and vegetation arable classes as NoData. The resultant land cover maps for both dates from Composites 1 are shown in Figure 5.

In order to qualitatively assess the resultant land cover maps, assessment data were used comprising 29 polygons for the classes listed in Table 2. Such assessment data were independent data, not used for the MLC process and, as in the case with training samples, were identified through visual interpretation of the Sentinel-2 data and aerial orthophotos. Examples of the comparison of the MLC pixels extracted over the assessment polygon areas are provided in Figures 6 and 7 for the 06/08/2017 and 25/10/2017 images, respectively. Assessment polygon areas ranged between approximately 9,000m^2 to 13,000 m^2. Areas of vegetation were classified relatively correctly (Figures 6a and 7a), whereas in smaller areas with hybrid classes such as urban areas (Figures 6b and 7b) and bare surface areas, the presence of mixed pixels was likely to affect the class spectral signatures and the resultant classified data.

Figure 5: Land cover classification maps derived for (a) 06/08/2017 and (b) 25/10/2017

(a) *(b)*

Figure 6: Land cover classified pixels extracted from assessment data over (a) vegetation non-arable, (b) urban and (c) bare surface inc. coast or quarry polygons of the 06/08/2017 MLC image

(a) *(b)* *(c)*

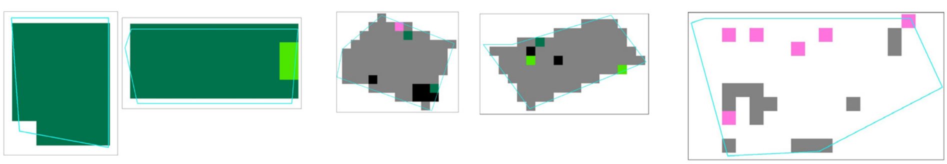
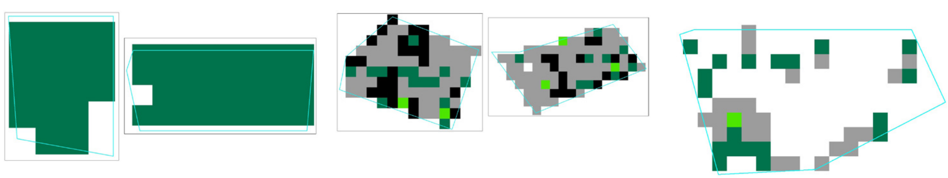


Figure 7: Land cover classified pixels extracted from assessment data over (a) vegetation non-arable, (b) urban and (c) bare surface inc. coast or quarry polygons of the 25/10/2017 MLC image

(a) *(b)* *(c)*



Conclusion

This study investigated the use of free and open Copernicus Sentinel data for assessing the land cover of the Maltese Islands. The high revisit time of the Sentinel images enables a temporal study of the covers with respect to seasonality. Preliminary results from this study highlight the interfering effect of mixed pixels on the classification algorithms. The small area of the Maltese Islands together with the high changes of land cover change within an area of $100m^2$ (i.e. one pixel) indicate high spectral heterogeneity present in classes over some terrain areas. This essentially contributes to misclassification of classes. This would be particularly significant should Sentinel-2 data be used for crop identification studies, due to the limited area of Maltese arable fields. Future studies will include a quantitative assessment of land cover, in addition to the qualitative assessment, as well as the use of alternative classifiers such as the random tree classifier. Furthermore, the availability of high-resolution satellite imagery over the Maltese Islands, such as those available from the ERDF SIntegraM project, would allow a comparative land cover assessment based on multi-spectral imagery and spatial resolution.

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Pivot II

Project based Approaches: Benefits gained from National, EU and International Projects Domain

Aerial Image: AI Generated Art
AI Art App - SF

CHAPTER 6

Strategy on a recoverable low cost UAS for wind field estimation along forest fires: the "HERO20FF" paradigm

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Introduction

Wind has a strong effect on fire behaviour due to fanning effects on fire and may present the most persistent problem in Forest Fire Management. It can change speed, direction, or become quite gusty. Wind influences the rate of spread and intensity of the fire. High winds cause the front of a fire to move ahead rapidly and may cause the fire to crown into the top of the trees and to jump barriers that would normally stop a fire. Moreover, high winds, updrafts & downdrafts occurring during the fire are important parameters, needed to be measured accurately on-site when the fire is in progress and probably out-of-control. This information is important for firefighting aircrafts when take-off, resources dispatching and the safety of firefighting personnel on the ground.

Hero20FF delivers a NewGen recoverable low-cost tube launched micro-UAV platform aiming to accurately estimate the wind-field along an erupted forest fire. The UAV will be managed real-time using a complete navigation system, comprising of both hardware & software modules, including both the airborne autopilot and a complete ground station mission planning and monitoring software utilizing a bi-directional datalink for telemetry and control. Real-time wind-field measurements are then mapped by the Hero20FF desktop application (Figure 1). The benefits Hero20FF offers is technology with major influence in thematic areas related to environment- and social-aspects. Hero20FF is directly connected with spatial visualization technologies, as namely GIS On-line and real-life applications.

Figure 1: Forest Fire Hero20FF Concept

Related Work (Background Knowledge)

Projects contributing to the project were:

- ArcFIRE™ a Platform managing Forest Fires (Figure 2)
- http://www.epsilon.gr/imported/files/brochures/54_LIFE10_ENV_GR_617_ArcFIRE_brochure.pdf
- LIFE+/ArcFUEL (www.arcfuel-project.eu) for forest fires fuel management
- ICT/PSP i-SCOPE (http://www.iscopeproject.net) that delivered a new ADE for the CityGML standard for Smart Cities and an OGC compliant OpenLS Routing Service extension and algorithms for routing of Disabled People.
- Seih-Sou/ArcFIRE (2009-11) ArcFIRE™, which is a market product (http://www.epsilon.gr/news/232). A scalable, modular, and customizable technology geo-platform that provides management solutions for the "entire spectrum" of the FF Lifecycle; as demanded by Civil Protection Authorities (National, Regional, State, Local), government and private operations.
- BRISEIDE: BRISEIDE (BRIdging Sources, Information and Data for Europe) "aim at delivering (1) time-aware extension of data models in the context of previous / ongoing EU INSPIRE related projects (eg in the context of GMES, eContentPlus), (2) application (eg, Civil Protection) based on the integration of existing, user operational information and (3) value added services for spatio-temporal data management, authoring, processing, analysis and interactive visualization.
- giCASES: The giCASES project developed new methods for co-creation of knowledge, where industrial partners and universities will jointly develop new case-based learning material based. The learning material and collaborative

teaching is tested at university settings. The case studies developed using a collaborative platform, where enterprises, universities and also students will collaborate. An application in Forest Fire Management has been completed.

Figure 2: ArcFire Technology embedded into Hero20FF (Epsilon, 2015)

UVision Ltd designed, developed and manufactured a unique, cost-effective, UAV system solution. Its core competencies include highly innovative aerodynamic platform configurations tailored for unique flight qualities, precision attack munitions, advanced airborne guidance and navigation systems and command and control stations fully integrated with communication links. Uvision Ltd unmanned vehicles technology has matured over more than six years of operational experience using unmanned vehicles of various classes. Throughout these years it developed and tested multiple technologies and approaches for remote command and control, imaging and video processing, air-ground communications, and man-machine interaction. The systems were tested in the field and user feedback was directly influenced the evolution of several generations of UVision's solutions, with all experience needed to develop a UAV/UAS for the Hero20FF platform.

Theorical Issues

Forest Fires is a constant threat to ecological systems, infrastructure, and human lives. The on-site and real-time meteorological conditions are one of the main and most important parameters for addressing fire risk during a dangerous occurrence. The timely and valid information about the current status of the meteorological observations (e.g., temperature, wind speed, wind direction) when the fire is in progress gives the opportunity to fire authorities to make an accurate and operational assessment of the evolution of the fire in a very short time.

Hero20FF

Hero20FF is a product that acts as means to stimulate the above concept in the following operational scenarios which cover two of the four phases of the Forest Fire Management Cycle, namely Emergency and Impact:

1. Scenario E1: Provision of accurate accessibility parameters through land observation. Due to the everchanging local meteo/wind conditions and fuel mass distribution, fire propagation can turn unpredictable and/or out of control. The identification of alternate access roads to the fire front in difficult accessible areas (e.g. mountainous terrain) is vital for approaching/firefighting during the emergency period;
2. Scenario E2: Real-time estimation of updrafts & downdrafts during the fire. High temperatures may cause local wind movements (up and side wind-streams) that cannot be easily estimated by ground or even by air (pilots') observations due to their proximity to the fire front. These streams can be indicated by an UAS at no risk for humans;
3. Scenario I1: Local wind calculation and rekindling fires. Prevailing wind characteristics at the affected areas can be captured and transmitted to the Control Center and incident commanders for rescheduling fire-bombing distances and directions; and
4. Scenario I2: Simulation scenarios and first responders' training and exercising. Fire-fighting scenarios and simulation exercises can be enriched with real time data and imagery taken by UAS at selected areas and hot spots. UAVs can also be used for post fire analysis and impact estimates in the affected areas.

User Needs/Requirements

UVision Ltd. constructed the micro-UAV platform. EPSILON set the requirements for the provision of the necessary meteo sensors and was responsible for the meteorological data measurements and their transmission to Control Command Centers (CCC). The General Secretariat of Civil Protection (GSCP) / Fire Brigade reviewed/validated user-requirements and tested the Hero20FF platform concept considering real case-studies.

Technology advancement

Hero20FF covers novel micro-UAV construction, sensors & monitoring systems, data transmission via terrestrial networks & satellites, a CCC linked to civil protection infrastructures, guidance to fire brigade, terrestrial & air operations inter-linkage and system optimizations correlated to all four stages of the FF life cycle, Geographic Information Systems (GIS), Information Communication Technologies (ICT) and geospatial technologies, offer trustworthy services to Civil Protection Authorities, Decision Makers, Incident Commanders and Fire Fighters.

The scientific & technological target of Hero20FF has been:

1. Micro-UAV usage to fulfill firefighting needs in both countries as well as firefighting requirements around the world;
2. Hero20FF to be an international and innovative best practice and justify innovative methodologies for wind field estimation along forest fires;
3. Collection and harmonization of meteo-data for real scale pilot areas;
4. Simulated Real life applications in the field at specified test areas, and validation of the system performance; and
5. Provision of critical information & assistance to Fire Brigades and other Stakeholders.

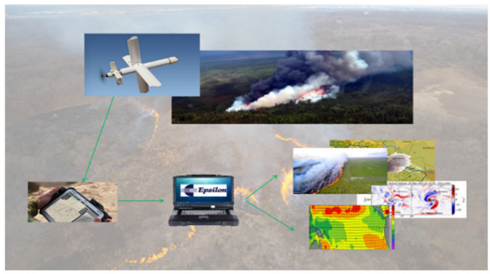
Knowledge Excellence

With the rise of forest fires in Southern Europe, the Mediterranean basin and around the world, and with climate change becoming a permanent and unpredictable reality, the need for a new solution is growing. The next step has been to employ the use of Unmanned Autonomous Systems (UAS) and Unmanned Aerial Vehicles (UAVs) instead of people to assess the situation and assist in putting out the fire from the air and the ground, and instead of putting firefighters into life-threatening situations, or at least to assist them in their dangerous tasks. This hampered by the limitation of all UAVs which require either a runway or a launching mechanism, making them incompatible with fast moving firefighting forces and manned observation towers. Hero20FF delivers a tube-launched micro-UAV which required no space or preparation for launch and is instantly available to the users who need it most.

Early detection of forest fires, and the management of large-scale fire-fighting operations, is currently performed with the aid of two types of observation systems: (i) Manned observation systems which include light aircraft and helicopters, as well as manned observation towers and (ii) Unmanned observation systems, which include ground based remotely-controlled day and night imaging sensors mounted atop observation mast, and unmanned aerial vehicles equipped with day and night imaging technology. Hero20FF stimulates the above concept. The technology behind is based on the construction of a novel micro-UAV platform, sensors & monitoring systems, data transmission via terrestrial & air operations inter-linkage and system optimizations correlated to all four stages of the FF life cycle. As results the project delivered (i) the NewGen recoverable low-cost micro-UAV platform aimed to accurately estimate and predict the wind – field along an erupted forest fire within a number of different scenarios, (ii) the Forest Fire Technology simulations s/w, as extension of the ArcFIRE technology, and (ii) real-life test firing and simulation results, as analyzed in the next chapter.

Figure 3: Hero20FF Launching

Figure 4: The overall concept of the Hero20FF Solution



Methodology Implementation

UAV & SENSORS

Hero20 is the smallest system in the UVision family of smart loitering. Deployable within minutes, it can reach 100 knots. It weighs 3kg and can carry a payload of 0.5kg. Its range is 40 km in 30 min. It has an electric motor with rechargeable battery. It is launched with an air-pressure canister and its landing is either with a parachute or in a net, and delivers the parameters: Wind Speed, Wind Speed Direction, Updrafts/Downdrafts, Air temperature and Real time Video (optical or IR sensor).

GCS-UVISION

The UAV is managed through a Ground Control Station based on the 10.1-inch Panasonic FZ-G1 fully rugged tablet. Engineered to withstand the hard knocks, drops and spills of real life on the road, the FZ-G1 is built to operate flawlessly in every environment — from intense heat and sunlight, to pouring rain and freezing temperatures. Running MS-Windows8 operating system, the FZ-G1 integrates seamlessly and securely with the Hero20FF Solution. It provides Mission Planning (touch screen or mouse), real-time video link, telemetry, and communication capabilities with the firefight management Ground Control Unit.

The GCS-UVISION gathers data from UAV and transmits its real time through a serial interface to GCS-EPSILON desktop for processing and mapping. Data: Time Stamp, GPS Latitude, GPS Longitude, Altitude, UAV Pitch angle, UAV Roll angle, Track Heading, UAV Heading, Air Temperature, and Indicated Airspeed.

GCS-EPSILON

The GCS-EPSILON implements the interface to the GCS-UVISION and performs necessary data pre-processing (complex computations, measurements interpolation). It also generates the data files to be used input for maps generation. The output includes: Air Temperature Maps, Air Updrafts/Downdrafts Map, Wind-Speed vector map, and Fire-front photo/video. The desktop application implements above and requires a laptop with minimum 4 GB RAM (8 GB suggested) and 20 GB disk space.

Triggering

Upon a Fire Alarm, the following steps are triggered:

1. Hero20FF Operator defines initial Area of Interest (e.g., a 3km × 3km square that surrounds the fire ignition point) and inputs it to the UVISION GCS.
2. Hero20FF Operator defines the waypoints of the flight plan and inputs them to the UVISION GCS.
3. Upon arrival at the fire location the operator selects an appropriate launching place, according to UVision's guidelines and prepares the launching equipment accordingly.
4. The operator launches the UAV
5. After launch and achievement of the necessary height the UAV starts its flight towards the first waypoint
6. The collection of data from all the installed equipment (sensors, cameras, and flight control system) starts.
7. The gathered measurements, data and photos are stored in a buffer memory in order to be transmitted to GCS if and when it is within communication range.
8. The UAV-to-GCS communication module forwards the buffer contents to the Ground Control Station. Live video Streaming from the fire front is also forwarded / displayed.
9. If the UAV passes through the last waypoint of its flight plan, then the landing procedure initiates. Otherwise, it adjusts its flight in order to travel towards the next waypoint.
10. At this point all UAV data is forwarded to the EPSILON-GCS subsystem through the Data Exchange interface.
11. The Data Exchange Interface splits received data in three distinct streams:

a. Real Time Video – this is displayed in the UVISION GCS

b. Sensors Data – Each "set" of sensors' data includes the respective GPS tag (X, Y coordinates) and AGL value, and the Temperature, Wind speed, Wind speed direction, Vertical Wind speed measurements. Other measurements, such as internal instrument temperature, remaining UAV Operation time, and Battery Voltage are provided from the UAV subsystem, although these are not used by the EPSILON GCS in the current application version.

12. Meteo sensor's measurements and data are pre-processed so to reflect a 50m×50m raster on the AOI map, using an interpolation algorithm. This data raster is then used by the desktop application to produce the respective maps
13. The EPSILON desktop application calculates and produces the maps: Horizontal Wind Speed maps, Vertical Wind Speed maps, Temperature Maps and Real Time Imaging.

    Note: Currently the maps are prepared and saved in the PDF and JPG format. Other formats can be considered depending on the specific requirements of each specific end-user/customer.
14. The above maps are forwarded to the responsible authorities, through Internet. The internet connectivity, for the purposes of this project/demo is considered as prerequisite. We fully acknowledge that this may not be true in several circumstances. There are alternatives, such as existing standard or proprietary military data communication networks, but alternative solutions are part of the future investigations for the Hero20FF.

Results and Conclusion

Hero20FF delivered a NewGen recoverable low-cost micro-UAV platform, aimed to accurately estimate & predict the wind-field along an erupted forest fire within a number of different scenarios which cover two of the four phases of the Forest Fire Management Cycle, namely the Emergency and Impact.

Benefits for the national economy, society, environment:

- Hero20FF is a smart/cost-effective complement to traditional manned aircrafts
- Hero20FF can perform dangerous missions without risking human life: natural disasters, large-scale forest fires, humanitarian relief, environment, weather & storm tracking,
- Hero20FF is capable to supporting basic assessment for wind and fire direction, of live video feed – real time monitoring for fire and wind direction changes and identification of hot spots,
- Hero20FF can save lives at natural and manmade disasters,

- Hero20FF is positioned to surveying damage, locate stranded and injured victims, and assess ongoing threats without risking the safety of rescue teams and first responders.

Note

This chapter was drafted in 2018 as part of the collaboration between the authors and the Maltese SIntegraM project. The indicated data and datasets are updated over time and can be reviewed through the relative links. This Chapter forms part of the Hero20FF project and is aimed at describing the project from a spatial analytical perspective. All rights remain those of the programme.

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CHAPTER 7

A novel approach for ultraviolet radiation & ozone retrieval via Copernicus for applications: the AURORA paradigm

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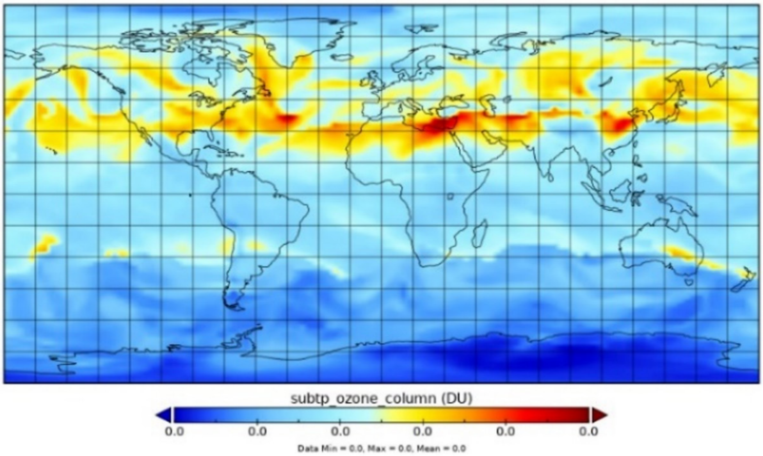
Vasiliki Palla

Introduction

Ozone is a key atmospheric constituent in all layers of the lower atmosphere. Stratospheric ozone is the most important radiatively active trace gas and essentially determines the vertical temperature profile in that region as well as the dynamics of air masses. Furthermore, it completely absorbs the UV-C solar radiation (280 nm), acting as a protecting shield. However, the UV-B radiation of longer wavelength (280-320 nm) can penetrate through the whole atmosphere down to the surface where its intensity is strongly modulated by the ozone column. UV-B harmful effects include damaging DNA, causing of various types of skin cancers, and eye cataracts.

In the troposphere (Figure 1), ozone affects not only the Earth's radiation budget by absorption of solar UV radiation, but it also acts as greenhouse gas by absorption of the terrestrial radiation near 9.6 μm. Down at the surface, ozone damages forests and crops and when ozone pollution reaches high levels in densely populated urban areas, it is a threat to people with respiratory problems. Because ozone in the troposphere is toxic to all living organisms it is often referred to as 'bad' ozone, by opposition to the 'good' stratospheric ozone, which protects us from the harmful solar UV radiation. Finally, ozone plays a key role in understanding the interactions between climate and chemistry due to active chemistry, which is influenced by atmospheric temperature and dynamics.

Figure 1 World Tropospheric Ozone Column



Source: Copernicus.org

Theorical Issues

Recent ozone monitoring instruments are proven essential to monitor the evolution of the ozone layer. However, due to the inherent limitations of each measurement technique, none of the existing systems can cover the needs for accurate ozone observations from the surface up to the mesosphere. Particularly critical are the lower troposphere and the UT/LS regions, which are extremely difficult to sense from space. Recent studies showed that ozone monitoring can be aided by synergistic data processing (Cuesta et al. 2013, Fu et al. 2013, Hache et al. 2014, Cortesi et al. 2016). Furthermore, surface UV data are available from very few sensors (Kujanpää and Kalakoski 2015). Although global UV data coverage can be obtained from Numerical Weather Prediction Models such as the UV processors created from the GEMS (GEMS 2018) and MACC (MACC 2018) projects, remains the need to investigate the influence of the tropospheric ozone in the estimated UV. Moreover, the tropospheric part could play a more significant role through combined influence of ozone absorption and enhanced Rayleigh scattering and aerosol scattering/absorption at the tropospheric levels.

Target to AURORA is to exploit the synergy between ozone measurements covering a wide range of spectral regions from the UV to the thermal infrared, and develop new innovative data fusion and assimilation techniques, to improve accuracy and vertical resolution in the troposphere. The system combines observations performed in different spectral regions by instruments operating on-board the geostationary (GEO) satellite Sentinel-4 and the Low

Earth Orbit (LEO) satellites Sentinel-5P and Sentinel-5 by assimilation of fused data. The primary objective is the reduction of the complexity of managing the high volume of data provided by Copernicus and increase its quality with respect to the operational outcome of individual instruments. This is done by designing and developing prototype data processing system capable of conveying the complementary information content of measurements acquired by the atmospheric Sentinel missions of the Copernicus programme into unique geophysical products. To this end, the project aims to:

- Investigate, enhance, and implement state-of-the-art methodologies for ozone and UV which will be applicable on an operational basis;
- Investigate, enhance, and implement an advanced state-of-the art surface UV processor, complementary to the existing ones developed by GEMS and MACC and to guarantee increased accuracy for the ozone profile, particularly in the troposphere;
- Demonstrate potential applicability to other atmospheric targets (e.g., SOx, NOx) and to become available for the generation of a wider set of advanced products;
- Develop applications to make use of the developed datasets;
- Deliver a system close to operations as far possible;
- Offer data sharing through a comprehensive and effective manner; and
- Disseminate scientific research & commercial exploitation of Copernicus

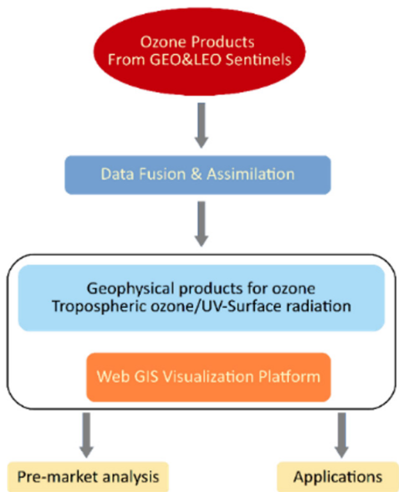
Theme II / VI / VII / VIII

Through the infrastructure developed in AURORA, information related to ozone concentrations and UV radiation is provided in unprecedented timeliness and precision. This results into significantly wider use of Copernicus Sentinel data and increased awareness with users of satellite data. Furthermore, commercial, and operational opportunities are stimulated by developing innovative applications which take advantage on AURORA datasets (Theme II). Geographic Information technology enables easy data sharing to potential stakeholders and raises users' awareness on the satellite data use. User-Centred Design (UCD) and smart dashboards are exploited to facilitate data visualisation and interface customisation to users (Themes VI and VIII).

Theme I / Methodology

Figure 2 presents an overview of the AURORA methodology. At first, simulated data are created as a pre-processing step. Through fusion of the same variables from Sentinel 4 and 5, synthetic images are created which are provided as input to the assimilation process where the final ozone and UV products are computed. The products are visualized through a web GIS platform, and are shared through web map sharing mechanisms, enable integration with applications requiring atmospheric data. GEO and LEO Sentinel datasets are currently simulated. Through, data fusion, and assimilation of the GEO and LEO datasets, the AURORA products are created. These are distributed through the web GIS platform providing visualization capabilities and the means for AURORA data integration in real-life applications.

Figure 2 AURORA methodological concept.



Data simulation

Since S-4 and S-5 were not operational at the time of this study, synthetic data were required for further analysis. To this end, atmospheric scenarios were established, describing the state of the atmosphere like Gelaro et al. (2017). Furthermore, simulated trajectories, observation geometry angles (e.g., zenith angle), and observation times for Sentinels 4 and 5 were created. These data were employed in the simulation of the acquisition of VIS (visual) TIR (Thermal Infrared) and UV and thus producing the synthetic Sentinel 4 and 5 data. The simulation period covered the 1 of April to 31 July 2012 for both sensors. To compute the simulated imagery timely, it was decided to reduce the number of pixels in the final images. Thus, image pyramids were created. For Sentinel 4 10% of the original number of scanlines and 10% of the original number of pixels per scanline were computed for all bands. For Sentinel 5, it was decided to sample each band differently. For the VIS, 1/7 of the original number of scanlines and pixels per scanline were computed. For the TIR 1/5 of the original number of scanlines and 1/4 of the original pixels per scanline were computed. For the UV, all pixels were simulated. Finally, only pixels having a cloud fraction less than 1% were considered.

Data fusion and assimilation

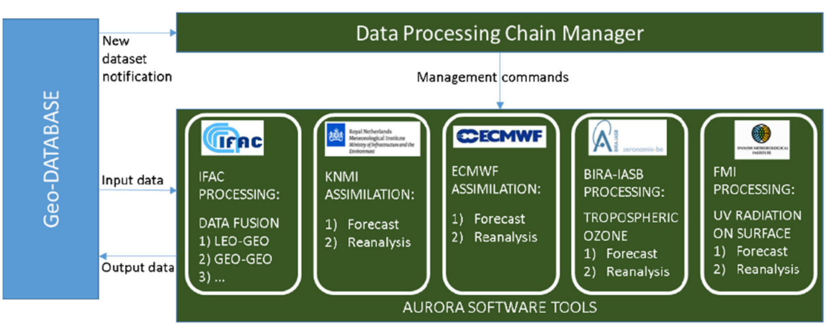
Through data fusion, the same geophysical parameters measured from different sensors (i.e. Sentinel 4 and 5) are fused into single estimates. Through this process a comprehensive, concise, and more accurate description when compared to the original data is computed. A new version of the Complete Data Fusion (Ceccherini et al. 2015) was developed to address coincidence and interpolation errors (Ceccherini et al. 2018).

The output of the Data Fusion process is provided as input to the assimilation process. Two Data Assimilation algorithms are used the IFS developed by the ECMWF and the TM5DAM developed by KNMI. The IFS is a comprehensive Earth-system model to simulate the atmospheric dynamics and the physical processes that occur in the Earth. Observations, including those for ozone, are assimilated in 12-hourly time windows with a four-dimensional variational data assimilation scheme. TM5DAM is a global chemistry-transport model, based on TM5 (Krol et al. 2005, Huijnen et al. 2010), designed to simulate the concentrations of atmospheric trace gases (e.g., carbon dioxide, methane, O3, etc.) To simplify computations, only O3 and its variance are modelled as tracers.

AURORA data handing and data processing chain

To manage the big amount of data (satellite imagery, intermediate, and final products), a big-data infrastructure was created, deployed on cloud infrastructure. The infrastructure was designed to enable quick data acquisition, harmonization (reprojection, noise removal, etc.), simulation, processing, and archiving activities (Figure 3). At the core of the system, a geospatial database is placed from were where all datasets are stored and retrieved.

Figure 3. AURORA methodological concept. The data processing chain integrates multiple modules to compute the final ozone and UV products



The described methodology for the computation of ozone and UV products, is executed by the AURORA data processing chain (DPC - Figure 3). Each of the DPC components (i.e., the geo-database for all data storage and the individual AURORA tools) are considered as separate system-independent entities. The DPC Manager thereby coordinates the processing between various AURORA tools and the geo-database where all datasets are stored. DPC Manager is waiting for new data to be available, and, upon their occurrence, to start their elaboration by invoking the proper tool and by providing information about new data received. Several implementation options for the AURORA tools are available means that several possibilities exist for the definition and integration of the data notification, data ex-change, and DPC manager (commands).

Remote accessibility and data illustration

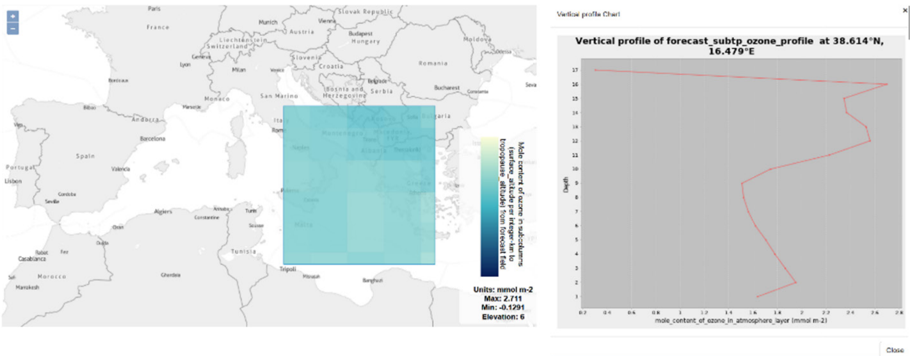
Target was to provide the necessary software components and enables efficient data access both to machine-to-machine processes and to smart dashboards for user-friendly data visualization of the AURORA products. To this end, a web service is developed according to Open Geospatial Consortium (OGC) international standards. The web service manages requests received from externals and allows for efficiently access of the data elaborated and stored by the internal infrastructure to reply to the requests received. In this way, AURORA datasets can be integrated to any GIS-based application since they are shared and publicly available through the Web Map Service (WMS) protocol.

The smart dashboard interface to the AURORA system allows non-IT technical users to personalize the view and provides tools to exploit the available data. This smart interface can provide (in a user profiled way) key parameters calculated by the AURORA system (ozone and UV related data, along with intermediate datasets for project partners to support research tasks) through user-friendly indicators and graphs. Available tools in the platform are (Figure 4):

- Rectangle Selection: Select a certain rectangle on the screen and display the data within the rectangle
- Download map: Provides for download a snapshot of the displayed map
- Download map as km2: Exports the provided map to km^2 output – compatible with Google Earth and other GIS software
- Download raw data that enables the user to download the fused LEO/GEO raw data
- Vertical profiling: Display the concentration of a certain variable over a single area

Figure 4. Examples of the data visualization tools. (a) rectangle selection of ozone coverage over a certain area. (b) ozone profile computed at a certain point of earth's surface.

(a) *(b)*



Dissemination and exploitation

The AURORA data that will be generated when Sentinel 4, 5 and 5p are operational enables a whole range of services and applications. The expected improvements in temporal-spatial resolution make the data relevant for organizations in the health community that need air quality and/or UV data. Multiple groups will benefit from these data, which are for example: cities that need a better understanding of the air quality in their region, tourists that take a sunbath that need information about UV exposure, and asthma patients who could prepare themselves when they see that air pollution increases.

Health problems related to air pollution and UV are well known. It is estimated that there are 235 million asthma patients, and 132.000 melanoma skin cancers worldwide. To get a better understanding about the impact of UV and air pollution, accurate and frequent monitoring is crucial. The current Sentinel 5p satellite, and the future Sentinel 4 and Sentinel 5 will provide information to understand changes in air pollution and UV. Furthermore, trends can better be assessed. AURORA collaborates with satellite-based initiatives such as GEMS (South-Korea) and TEMPO (US), which enables deployment of applications worldwide.

Use cases of AURORA

Below we discuss multiple types of applications for AURORA data products in relation to air pollution and UV.

Air quality monitoring for cities

Increase in urbanisation leads to increasing amount of people that live in cities with severe consequences related to air pollution. Local governments develop and implement policies related to air pollution, and they need reliable information to monitor the effectiveness of policies and intervene if necessary. AURORA data products provide a new source of information for local governments.

Application for 'sunny' tourists

Many tourists tend to go to sunny places for a sunbathing. Extensive exposure to UV can have negative consequences for their skin and health. A smart phone-based application that includes near real-time data (powered by AURORA) warns for the effects of UV exposure and helps tourists to protect themselves from the sun.

Protection for employees that work open air

Many jobs require extensive time working outdoors, which means that employees are exposed to air pollution and UV. For employees and their employers, it is important to understand the risks and to decide how to increase the safety of working outdoors. Applications based on AURORA data help to quantify the risks and increases a safe working environment.

Conclusion

AURORA integrates multi-disciplinary knowledge and techniques of scientific and technological excellence. State-of-the-art methods have been investigated and integrated in a complex architecture to compute ozone and UV datasets from Sentinel 4 and 5 data. Although the examined data at this point are synthetic, minor adjustments are expected when the real satellite data will be available soon. The entire infrastructure was developed to ensure that the unprecedented source of operational satellite data can be widely used by academicals, industry, and operational actors. It allows European and international users to cope with data storage, processing, access, and sharing with a view to using it to address some of the grand socio-economic challenges faced today. Thus, it is considered close to operational, although it is expected that when the Sentinel 4 and 5 sensors are launched, adjustments will be required to eliminate the use of synthetic datasets and integrate the satellite acquired data. Applications to benefit from AURORA datasets are examined, and it is expected to be developed and deployed as a proof-of-concept of the AURORA data capabilities. The impact of this investigation is the fact that scientific results can be directly employed in real-life applications, thus reducing the gap between science and commercialisation.

Note

This chapter was drafted in 2018 as part of the collaboration between the authors and the Maltese SIntegraM project. The indicated data and datasets are updated over time and can be reviewed through the relative links. This Chapter forms part of the AURORA project and is aimed at describing the project from a spatial analytical perspective. All rights remain those of the programme.

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CHAPTER 8

Integrated management of water-land-food-energy-climate (NEXUS) for a resource efficient Europe: the SIM4NEXUS paradigm

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Vasiliki Palla and Despina Kallidromitou

Introduction

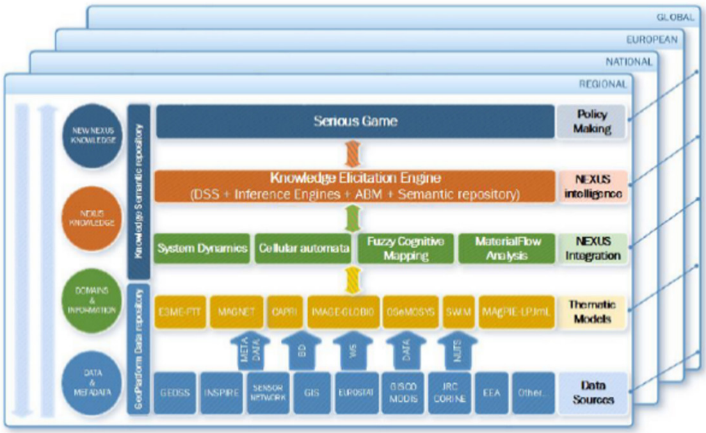
Europe's economic prosperity and well-being is intrinsically linked to its natural environmental- from fertile soils to clean air and water. Natural resources (both renewable and non-renewable) allow the functioning of the economy and uphold our quality of life. Specifically, global competition between land, water, and energy resources is increasing and is exacerbated by climate change. The global demands for natural resources, are caused by the growth of global population. Such trends, lead to urbanization and changes in consumption patterns. Continuing current trends in the use of these natural resources means that nations are living beyond their biocapacity, thus creating an ecological deficit.

Relative Work

There are many different types of quantitative models available. Not all modelling approaches are relevant to the analysis of nexus-related policy, but it is still useful to be aware of the potential options available, for example to guide future development. From the modelling approaches that are typically used to assess the economic impacts of alternative climate policies and energy strategies, the most widely used models fall under the following categories.

- Computable General Equilibrium (CGE) models: Optimization models founded on neoclassical micro-economic foundations, capturing the interactions of all markets and economic agents. These models are often criticized for their assumption of full employment of resources and a lack of representation of market failures (Dixon & Parmenter, 1996). MAGNET (Modular Applied General Equilibrium Tool) is a global general equilibrium model. The modular design of this model allows modelers to tailor the model structure to fit the research question at hand. MAGNET offers more flexibility in model aggregation (definition of regions and sectors) and more options for changing a model's structure (Figure 1).

Figure 1 SIM4NEXUS Overview structure



- Partial equilibrium models: Optimization models founded on neoclassical micro-economic foundations, which takes into consideration only a part of the market, ceteris paribus, to attain equilibrium, based on restricted range of data. The use of the CAPRI modelling system, which is increasing, and the user group becomes more diversified is representative example of partial equilibrium models.
- Macro-econometric models: Econometrically estimated models with a high degree of realism. These models typically do not assume full employment of resources. Their validity can be questioned when the scenario that is being modelled is far away from the experience of their estimation domain (the Lucas Critique). E3ME is a computer-based model of the world's economic and energy systems and the environment, originally developed through the European Commission's research framework programmes. Now is widely used globally for policy assessment, for forecasting and for research purposes.
- Bottom-up engineering models: Models that provide a detailed and realistic representation of an isolated sector/part of the system, for example energy or land use. On their own, they lack feedback loops with the rest of the system.
- Climate models: Models of the dynamics of the earth's climate system, using a simulation approach. Climate models vary considerably in their degree of complexity but focus exclusively on the planet's natural systems (Hasselmann, 1976).
- Large-scale Integrated Assessment Models: Tools that combine the model types described above, including a representation of the climate system. Often the

large-scale IAMs combine other distinct tools and linking these tools is a key challenge (Ackerman et. al., 2009). Representative example is IMAGE, which is a comprehensive integrated modelling framework of interacting human and natural systems. Its design relies on intermediate complexity modelling, balancing level of detail to capture key processes and behaviour, allowing for multiple runs to explore aspects of sensitivity and uncertainty of the complex, interlinked systems.
- Small-scale Integrated Assessment Models: Models that integrate different system processes into a unified framework with the aim of optimizing outcomes across the whole system. These models have been heavily criticized for their ‘reduced form’ nature and simplified representation of complex economic structures (Ackerman et. al., 2009, Pindyck, 2013, & Stern, 2013).
- Agent-based models: Models that focus on the interaction of autonomous entities according to rules specified by the modeler. Typically, a stochastic process is applied, and the set of simulation results is analyzed to examine the properties that emerge with the greatest frequency. These models may be used for theoretical analysis, where simulation is the only feasible way of obtaining results; typically, there are challenges in parameterizing and validating models in relation to historical experience (Bruch & Atwell, 2013).
- Bayesian network models: These models use probabilistic relationships to describe the connections of agents. They are strong in treating uncertainty but poor in considering feedback loops and in providing precise causal relationships (Jensen & Nielsen, 2007).
- Systems dynamics models: Models which identify and map the structure of systems, and the feedback interlinkages between elements within them. Computer simulation enables the modelling of behavior resulting from complex, non-linear feedback relationships within a system.

Theorical Issues

Nowadays, ecological integrity of river basins is compromised, land use changes drastically over short time periods, and poor water management together with climate change will increase the risks of both floods and droughts. Moreover, there are several problems that slow the EU’s rate of transition to greater resource efficiency. SIM4NEXUS faces the following challenges.

- Policy inconsistencies and incoherence reduce predictability and response adequacy: policy made for a good reason in one field can have unintended consequences that hold back efficient resource use in another.
- The existence of knowledge gaps about the future risks constrains policy-makers from future planning make the future uncertain; these significant uncertainties focus on how environmental systems will change and the impacts they will have,

which leave policy makers unaware of risks in complex, global supply chains.

- Knowledge and technology lock-ins exist when established ideas or practices have a price advantage over innovations, or where they form part of a system of which the other parts are not changing.

Aim of this project is to examine the cross-correlation, relevance, and implications of five distinct nexus (land, food, water, energy, and climate) with the parameters of society, economy and policy, to give future solutions and strategies for a sustainable Europe. Serious Game, will invest in innovation for a green economy, will achieve progress in social and public sector innovation. The overall work plan is built around the 12 case studies of SIM4NEXUS, which will act as a testbed and a showcase of all the tools and technologies developed in the project. An additional aim of SIM4NEXUS is to display the implementation of the SIM4NEXUS methodology, through a network of regional and national case studies. These aims will be achieved through the following objectives.

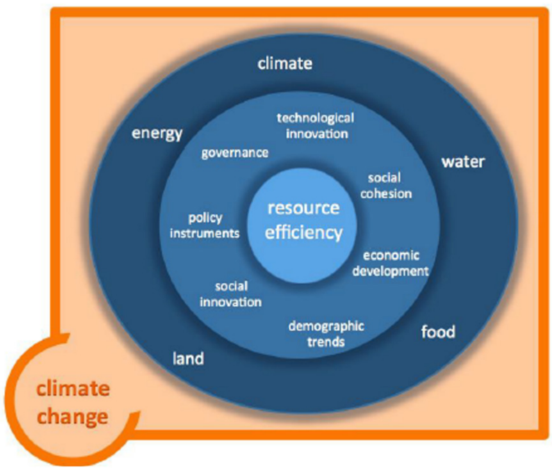
- To adopt existing knowledge and development of a new Nexus expertise, supporting the goals of the EU 2020 vision for smart, sustainable, and inclusive growth, by testing improvements in resource efficiency and low-carbon energy use.
- To examine advanced integration methodologies based on Complexity Science approaches to bridge the knowledge gap related to the complex interactions among all components in the five Nexus.
- To implement a Serious Game as an intuitive means to aid end–users and policymakers.
- To implement a business plan to valorize the project outputs (Complexity Science Nexus integration tools, Serious Game, Knowledge Elicitation Engine) by creating project spinoffs.

SIM4NEXUS aims to offer long-lasting, economically sustainable exploitation of its results, including an Intellectual Property Rights (IPR) legal framework for the partners and a mechanism aimed at encouraging and accepting new partnerships in the years to come. These challenges are addressed by developing innovative methodologies to facilitate the design of policies and bridge knowledge and technology gaps in the field of the five examined Nexus components under climate change conditions. SIM4NEXUS develops a methodology of integration using a complexity science approach and a Serious Game, as an integrating tool for testing and evaluating policy decisions. The Serious Game is operable at different scales ranging from regional to national, to continental, to global, as well as at different time horizons—short, medium and long-term.

Theme IV/V

SIM4NEXUS thematic areas are related to the Environmental as well as to the Social Aspect. Specifically, the structure of the project, is based on the interconnection of environmental resources such as land, food, energy, water and climate. Additionally, relevance and implications of these five resources with the complexity of the parameters of social, economic and policy, will give future solutions and strategies for a sustainable future Europe. The integrated management of the Nexus is critical to secure the efficient and sustainable use of resources. Figure 2 shows that social parameters such as social cohesion, social innovation, take part in the vision of the Nexus concept. One of the core elements of multi-sectoral strategies, adopted as a general target, the resource efficiency. In each policy area and for each policy instrument, appropriate analysis must be carried out using evaluation and impact assessment processes.

Figure 2 Vision of the Nexus Concept



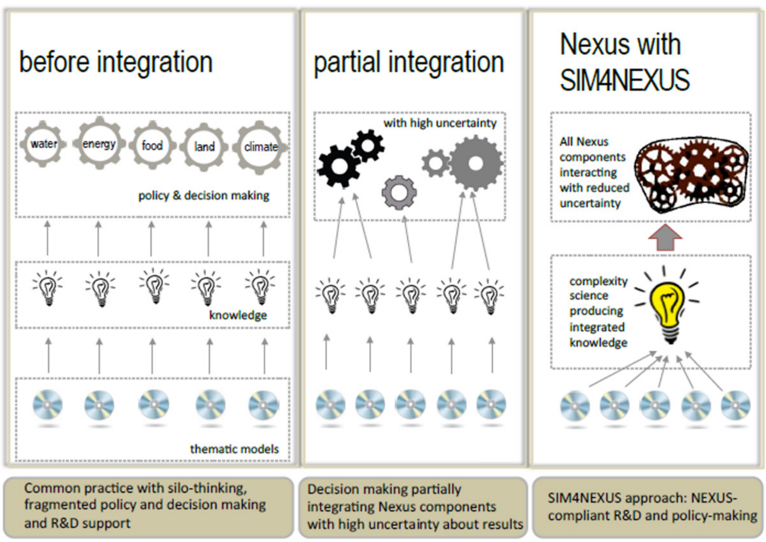
Methodology and Implementation

SIM4NEXUS proposes a cloud-based, integrated resource-use Serious Game, acting as a policy assessment tool that bridges the Nexus knowledge gap effectively, by providing an immersive experience to the user. It is designed to be used primarily by authorities and policymakers at all levels (regional/ national/ continental/ global) and allows them to identify critical areas of the Nexus, to evaluate and quantify the effects on resource levels of new policies and subsidies, of climate change and mitigation practices, of the implementation of technological and social innovations, of adopting low-carbon options, of new investments and interventions, etc.

SIM4NEXUS provides a central knowledge base to feed the different Nexus methodologies, supporting (i) the gaming tool (to train actors in a common area of interest), (ii) the decision tool (supporting managers and operators), (iii) simulation tolls and (iv) various gaming tools depending on spatial scale.

A schematic overview of the SIM4NEXUS concept is presented in Figure 3. When the Nexus is not considered, and knowledge remains compartmentalized in different silos, we obtain policy- and decision-making that lacks integration and is inconsistent and incoherent (left panel). Recent trends reflect partial integration (e.g., the water-energy nexus) and produce results based on fragmented knowledge and loaded with high uncertainty (middle panel). SIM4NEXUS is based on thematic models but uses complexity science approaches to integrate results producing unified knowledge; this way, all components interact together producing results and Nexus-relevant policies with reduced uncertainty (right panel).

Figure 3 SIM4NEXUS Concept



Methodology Steps (1-7)

1. Understanding/Assessing Nexus in various contexts

Aim of the first step is the development of the Framework for the assessment of the Nexus to be used in the case studies and to identify suitable innovations/low carbon options to be implemented in the case studies. Specific objectives are as follows.

- Design of SIM4NEXUS Use Cases,
- Review the SIM4NEXUS Thematic Models in their capacity,
- Address the Nexus and cover policy domains, while at the same time, identifying key gaps that need to be addressed,
- Conduct an uncertainty analysis that will cover issues related to where it stems from and how it affects decisions,
- Development of the SIM4NEXUS Framework for the assessment of the Nexus in the Case Studies,
- Providing narratives for scenarios and specify innovations through a Nexus Dialogue with the stakeholders to be run by the Serious Game and
- Assess the performance of interventions decided by stakeholders through benchmark values and Key Performance. Indicators are custom developed for each case study.

2. Policy analysis of the Nexus

Policy Analysis of the Nexus is based on analyzing the policy coherence for the Nexus at different scales and different phases of planning and implementation. It provides a better understanding of how the Nexus-relevant and related policies (e.g., biodiversity and Sustainable Development Goals) are linked. The specific objectives were as follows.

- Identification and review of the critical policy areas relevant to the Nexus across scales, considering near- and long-term policy initiatives and objectives.
- Analysis of interactions, coherence, or conflicts between policies and identify trade-offs. This will consider how ‘nexus compliant’ current policies are.
- Provision of recommendations on these policies especially for removal of implementation barriers; and
- Development of systemic, integrated strategies and approaches towards a resource efficient and low carbon Europe. This WP provides increased understanding of how water management, food and biodiversity policies are linked together and to climate and sustainability goals.

3. Thematic Models and their Integration Approach

SIM4NEXUS organizes and carries out the application of the thematic models for partial simulation of the Nexus components of the Case Studies under different scenarios. Then, it collects and organizes the data from these runs into a semantic database that is used for the complexity science tools to be developed for the integration. In addition, it reviews and selects the most suitable integration methodologies to develop the science models for the Case Studies and the serious game. These science models then run for many scenarios. The outputs from these runs are stored in the semantic database, to be used for the serious game. Consequently, the specific objectives of this phase include.

- Selection and adaptation of the thematic models suitable and needed for each case study
- Downscaling and formulation of the necessary climate/climate change and socio-economic scenarios as needed for the implementation of the thematic models
- Application of the thematic models, as needed for the case studies (in coordination with step 5)
- Collection and organization of the inputs and outputs from the thematic models in a database, so that they can be accessed and used by the integration algorithms
- Review and selection of appropriate complexity methodologies and integration approach(es) suitable for each case study.
- Development of complexity science tools at a higher level of integration and lower level of detail, for the needs of the serious game.
- Implementation of the complexity science models for the case studies, running hypothetical scenarios.
- Storage and organisation of the inputs/outputs and other types of information (e.g., constraints) of the hypothetical scenarios in a semantic repository (database).

4. Serious Game Development and Testing

The development of SIM4NEXUS, focuses on defining, implementing, testing, and validating the Serious Game. The Serious Game assists policy makers and stakeholders to better understanding and visualizing policies at various geographical and temporal resolutions, leading towards a better scientific understanding of the NEXUS. The specific objectives of this phase included.

- Definition and implementation of the game strategy, users, roles and storylines, examining temporal (short, medium and large) and geographical scales (regional, national, European and global) and promoting 'learning by doing' where the users will learn from wins and losses.
- Determination of gaming objectives that permit to understand how complex social-technological water-energy-food systems work under climate change and how to manage the water resources.
- Definition and collection of the information requirements among all platform components and flow.
- Definition and implementation of the mechanisms to accumulate learning from users, incorporating the learnt knowledge into subsequent rounds, and to learn from Nexus knowledge and integration methodology.
- Definition and implementation of a GUI to permit the users to play and re-play scenarios, modifying real-life variables to test changes in components and outcomes.
- Validation of the solution in a development environment

5. Implementing the Nexus-compliant practices

SIM4NEXUS supports the implementation of Nexus-compliant practices in Europe. The methodologies of integration and tools of integrating the Nexus components are applied, addressing real-life challenges in 12 selected case studies at regional, national, European and global scales. A science-policy participatory process is established, guiding end-users towards Nexus compliant practices that supports a resource efficient Europe. More specifically, the step's specific objectives included.

- Application of the SIM4NEXUS concepts, assessment frameworks and tools to address real-life Nexus challenges in selected case studies representing a diversity of scales for decision-making, as well as socio-economic and institutional conditions. These real-life applications in particular focus on the role and added value of:
- The SIM4NEXUS framework developed in the first sector of understanding Nexus in various contexts;
- The complexity science framework developed in the sector of Thematic Models and Methodology of Integration, to support decision making and identify policy recommendations that are Nexus-compliant;
- The Serious Game developed under step 4, raising awareness on the Nexus challenges. To establish a Nexus-compliant society, behavioral changes are required, both currently and in the future, by citizen, economic sectors, and decision makers related to the Nexus. These applications are carried out within participatory processes that closely associate relevant stakeholders and end-users of the SIM4NEXUS products to research activities. In line with the principles of participatory science and the living-lab concepts, end-users are associated to research activities for: (a) specifying their demand in terms of tools for addressing Nexus challenges (input to steps 3 & 4), (b) applying the tools developed by SIM4NEXUS and (c) evaluating the added-value of the SIM4NEXUS tools (input to steps 3 and 4).
- Investigation and development of tools applicability and relevance for supporting decisions and raising awareness to other parts of Europe (regions, countries, transboundary river basins etc.) that have not been investigated in detailed case studies. Overall, this paves the way to the legacy of SIM4NEXUS and future dissemination and use of its results/products.
- Contribution to the development of guidance for effective policy adaptation and implementation that supports a NEXUS compliant resource efficient Europe (input to step 2).

6. Exploitation Impact and SIM4NEXUS Business Plan

This step aims at preparing the exploitation of SIM4NEXUS. Target are as follows.

- Market exploration for the different outputs of SIM4NEXUS already from the project start
- Assessment and watch competition
- Set up an ecosystem around SIM4NEXUS
- Definition of the product and services that can unleash the maximum exploitation potential
- Identification of the optimal business models and exploitation strategies
- Business plan with the propositions for one or more potential marketable products

Preparation for the creation of one or more project spinoffs

7. Dissemination and Communication

The Step 7 of the project is crucial for achieving the project's impacts, in those areas where windows of opportunities have been identified (e.g., IPCC AR6, WFD). It targets a broad spectrum of audiences, with a clear priority on decision-makers for the individual resources of the Nexus and researchers (e.g., related to IPCC). Targets are as follows.

- Effective dissemination, communication, and interaction with the potential (end) users of the outcomes and products resulting from SIM4NEXUS
- To stimulate discussions, support decisions and popularize the SIM4NEXUS gaming method at the main levels (regions, countries, EU) among stakeholders (step 2) and scientists (step 1) and interested communities (steps 4-6)
- Identification, specification, and clarification of research questions as response to communication/dissemination feedbacks
- Contribution to the IPCC AR6 review process with own ensemble-oriented results about the Nexus.

Results and Conclusion

- It is challenging to link the modelling tools due to the different natures of their coverage, for example level of detail in geographical detail or length of forecast horizon. It should also be noted that the project includes both optimisation and simulation models, which have different underlying assumptions that require careful consideration when linking.
- There is some crossover in model capabilities between the different tools available, they allow a comparison between different tools – giving insights into the importance of different assumptions or approaches and allowing some assessment of risk/uncertainty in the model outcomes.
- There is a toolbox at disposal from which models with the most appropriate

coverage can be selected across the different dimensions assessed. The developers of the serious game, in conjunction with the systems dynamics modelling and the complexity analysis, also have a set of tools that they can draw upon.
- SIM4NEXUS approach is innovative, since the interconnections of sustainability-related concepts are investigated, explicitly represented, and exploited through an intuitive approach, i.e., the Serious Game. In mid-2019 the first concrete results will be available for evaluation and discussion.

Note

This chapter was drafted in 2018 as part of the collaboration between the authors and the Maltese SIntegraM project. The indicated data and datasets are updated over time and can be reviewed through the relative links. This Chapter forms part of the SIM4NEXUS project and is aimed at describing the project from a spatial analytical perspective. All rights remain those of the programme.

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CHAPTER 9

Space Research Fund: building capacity in satellite earth observation research

Stephen Grixti

Introduction

We are increasingly living in a data-driven world. A significant portion of the world's running data archive is sourced through Earth Observation satellites, observing our planet for the ultimate benefit of all. This vast amount of data helps service providers, public authorities and other organisations improve the quality of life for their citizens. This key source of information is becoming an indispensable tool in helping us better understand and approach societal challenges. European investments into flagship programmes such as the Copernicus Earth Observation programme, and the associated free and open data policies, are today's catalyst for new products and better services.

Copernicus is served by a set of dedicated Sentinel family of satellites, contributing satellite missions and in situ systems such as ground stations, which deliver data acquired by a multitude of sensors on the ground, at sea or in the air. In addition to openly delivering data from this multitude of sensors, the programme also encompasses six value-adding services streamlined under six thematic areas, namely: atmosphere, climate, marine, land, emergency and security (European Commission, 2018). The Copernicus Programme is hence increasingly regarded as a notable contributor to the world's ever-growing data archive.

However, the extensive public funds going into such programmes can only be duly justified if this ever-growing amount of data and related services are appropriately consumed by the relevant entities. It is only through proper user uptake and operational exploitation that we can translate such a wealth of information into economic, societal and environmental benefits. It is only through having the right awareness; the right understanding of its validity across various sectors, that we can fully unlock its potential. It is worthless having a wealth of remotely sensed environmental datasets unless the concerned authorities consider them in impact assessments to aid urban planning while protecting natural habitats. It is pointless having the facility to rapidly request high resolution satellite imagery over an area of interest at no cost unless this capability is exploited in securing our coastal waters or in aiding decision making in emergency situations. It is meaningless having datasets that stretch back for years, unless these are used in recognising patterns, identifying anomalies and generating better forecasts. It is futile having gigabytes of remotely sensed freely available information over Malta every couple of days unless it is consumed and condensed into mere megabyte documents comprehensible by policymakers, legislators and the authorities making decisions impacting generations to come.

As identified through a satellite data user uptake study (European Commission, 2016) performed by the European Commission to help formulate a user engagement strategy for its Earth Observation programme, the Maltese user community has an overall low awareness of the potential of satellite-based observation services, such as those emanating from Europe's Copernicus Programme. Consequently, this limits demand and willingness to invest in pre-processing services, diminishing any incentive on the private sector to diversify their portfolio and enter the downstream value chain. Often, the stumbling blocks are misconceptions. Misconceptions on the quality and quantity of data, on presumed complexities related to accessing, integrating and using it operationally. This is where the importance of a drive to enable the right mind-set comes in. In fact, the first National Space Policy, published in 2017 identifies the importance of laying the foundations for proper uptake through awareness raising and capacity building.

National Space Policy

The first Maltese national space policy (Malta Council for Science and Technology, 2017), published in 2017, recognises that the downstream space sector harbours potential which is still to be exploited. Further investment in this sector, which deals with the utilization of space data and related services, would enable public entities to deliver smarter services. This increases demand for solutions substantiated by space data that in turn encourages niche market downstream industries, particularly those with transferrable skills from the established ICT sector. Having identified a lack of awareness in Earth Observation applications as a bottleneck to the uptake of related services, the policy recognises a need to drive home the relevance of such space applications to everyday life and to tangibly link space activities to societal and economic matters in Malta. The Malta Council for Science and Technology (MCST), within the Parliamentary Secretariat for Financial Services, Digital Economy and Innovation, within the Office of the Prime Minister is the Governmental body entrusted with coordinating space-related matters in Malta. The Council has, in fact, over the past years been organising conferences, workshops and information sessions aimed at starting to enable the right mind-set when approaching the topic of satellite applications and related data. Such activities, often supported by expert entities such as the European Commission and the European Space Agency, targeted potential end uses of satellite-based applications such as public authorities, as well as the private and research sectors. Regularly, the council cooperates with other Maltese entities that seek to improve uptake within their relevant sectors. These include the Planning Authority (PA), the Environmental Resources Authority (ERA), the Armed Forces of Malta (AFM) and the Malta Communications Authority (MCA). The engagement of local public authorities brings to the table valuable networks and knowhow which is crucial in achieving wider participation.

The policy, however, does not stop at awareness-raising. It asserts that despite the importance of conferences, workshops and related events, a more focused capacity-building approach is often necessary. It is well recognised that training, collaborative and funding opportunities for research and innovation projects, as well as internationalisation efforts where possible, provide the means for developing critical mass. To further leverage capacity-building, the Council has engaged with foreign space agencies and other entities, to improve engagement by professional communities locally and in Europe. Such collaborations help bridge the gap between space and society, bringing Space technologies closer to Maltese citizens, companies and non-Space actors. Concrete and tangible capacity building measures, through intensified cooperation with expert entities such as the European Space Agency (ESA), are indispensable to reliably jump start the sector.

Relationship With ESA

ESA is often considered as Europe's gateway to space. Although not an agency of the European Union, the intergovernmental agency continues to cooperate with the European Commission on various projects. Most notably ESA is the technical architect of the EC's flagship programmes, Galileo and Copernicus. More specifically on the latter, ESA is behind the Sentinel family of satellites, which have been specifically developed for the operational needs of the Copernicus programme (European Space Agency, 2018).

Malta's relationship with ESA started in 2012. The Malta-ESA Cooperation agreement, which was recently renewed for an additional five years until 2022, started offering traineeship and fellowship opportunities to Maltese researchers. This was indeed a first and crucial step in starting to explore the opportunities harboured by a space sector. It was however immediately evident that while the space sector in Malta was in its inception phase, capacity-building measures became ever more critical. Training and collaborative opportunities for public-private projects, as well as internationalisation efforts where possible, where recognised as key means for developing critical mass.

Considering results of a 2015 ESA technical visit to Malta, and its willingness to maintain a continued momentum in the sector, MCST worked to intensify its relationship with the ESA and establish a €2 Million national fund exclusive to the Maltese space sector. The ultimate objective of the National Space Fund, which operates between 2018 and 2022, is to tangibly aid local capacity-building in line with Malta's current and immediate priorities. This national initiative, supported by ESA through an Implementation Arrangement signed in March 2018, is indeed a milestone within the Maltese Space sector. The fund establishes two priority areas over a five-year period: a Space Research Fund (Malta Council for Science and Technology, 2018) and a Space Education Programme (Malta Council for Science and Technology, 2018).

Figure 1 The National Space Fund (2018-2022) concretely aids capacity building in Maltese space sector

Credit: Contains modified Copernicus Sentinel data (2017), processed by ESA

Space Research Fund

A substantial part of the €2 million Euros National Space Fund is dedicated to the Space Research Fund, a national space research programme exclusive to Maltese beneficiaries (Malta Council for Science and Technology, 2018). The funding programme is coordinated by the Malta Council for Science and Technology as has been defined through technical contributions from ESA and Malta Enterprise. The Space Research Fund provides financial support for research, development and innovation in the downstream space sector, specifically research projects that deal with the processing and exploitation of data collected through Earth Observation satellites. Such projects often encompass research and development at the intersection of science and ICT and seek to translate the unprocessed and raw data delivered from satellites and other sensors into information that can be easily understood and used. The programme ran from 2018 to 2022 with yearly calls supporting 20-month projects up to a maximum of €150,000 per project.

Following up from the National Space Policy, this initiative makes available funding that enables non-space players to explore, trial and eventually take-up solutions that are substantiated by satellite data. This programme offers opportunity to public authorities and Governmental entities to explore the potential of solutions substantiated by satellite applications, enabling them to deliver smarter services, in less time and with less effort. It incentivises ICT start-ups and SMEs to explore the lucrative sector and consider diversifying their current portfolio of services. It enables academics and researchers to discover the power of satellite imagery, innovate and push the boundary of knowledge in utilising this extensive resource. Ultimately, it sets the stage for public, private and research organisations to come together and research, innovate and develop solutions that are valuable in an operational setting; solutions that can positively affect the lives of each one of us. It is only through such capacity building activities, that we can make small but concrete steps in enabling a mind-set shift that encourages the uptake of space applications.

While focused on national needs, the Space Research Fund provides due consideration to related European initiatives and programmes. Such consideration ensures European-caliber development that helps reduce disparities between established players and emerging ones like Malta. This approach would enable Malta to be in a better position in terms of accessing European Union funds and markets on satellite data and the eventual provision of new products and services. Such an initiative is a commitment to broadening the horizons of SMEs to an upcoming sector, by discussing their new ideas and ambitions. This helps shape a "relatively new economic activity that is complementary to Malta's efforts in modernising the industry through transforming it into a knowledge-based one. It supports the competitiveness of Maltese industry, stimulates national innovation and research, as well as fosters international cooperation. The diversification of company portfolios supports resilient economic growth that can ultimately translate into prosperity of Maltese citizens" (maltaprofile.info).

Research Streams

Considering the early stage of the local space sector, the Space Research Fund offers funding opportunities across the innovation chain, from early conceptual research to the development of technologies that are closer to market. This provides opportunities for innovation within the academic and research sectors while encouraging spin-offs and the diversification of start-up and SME portfolios. Moreover, this shall strengthen the nexus between academia and industry leading to operational technology transfer in a more structured and sustainable manner.

Consequently, the Space Research Fund accepts proposals under two different streams:

- Stream 1: Technology Concept Research (TRL 1 to 4)
- Stream 2: Applied Technology Development (TRL 5+)

The highest scoring proposals across both streams will be selected for funding. The number of projects selected for funding will correspond to the funds available under the programme. Additional information on the specific Space Research Fund streams is available in the associated rules for participation (Malta Council for Science and Technology, 2018).

Beneficiaries of SRF 2018

The Space Research Fund 2018 call for applications was open between 7th May and 2nd July 2018. The evaluation board, comprised of ESA experts and other independent evaluators, selected two proposals for funding: SAT-FIRE and PIXAM. Both projects, amounting to a disbursement of €150,000 each, started in September 2018, with the final results provided in May 2019.

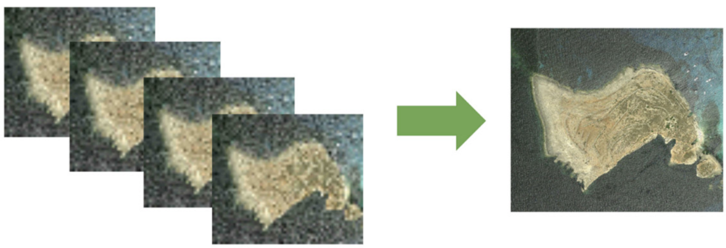
SAT-FIRE

The University of Malta, interfaculty project entitled "SATellite data Fusion and Imaging Resolution Enhancement for coastal areas" (SAT-FIRE) is led by Dr Ing. Gianluca Valentino together with Dr Ing. Reuben Farrugia (both from the Department of Communications and Computer Engineering, Faculty of Information and Communications Technology) and Dr Anthony Galea (from the Physical Oceanography Research Group, Department of Geosciences, Faculty of Science).

This interdisciplinary project lies at the intersection of satellite image processing, remote sensing, data fusion and hydrodynamical modelling. Two postgraduate students and a post-doctoral researcher will be engaged by the University of Malta through this project, to work on the data fusion and resolution enhancement, and the development of the registration algorithm, and to work on the improvement of hydrodynamical models for marine current prediction.

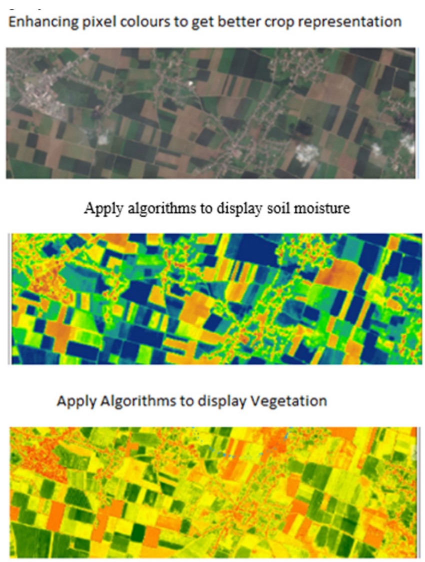
The main objective of this project is to improve the spatial resolution challenges of current Earth Observation Satellite systems by fusing complementary data from different spectral images from Copernicus' Sentinel-2 and Sentinel-3 data to improve both spatial and temporal resolution and quality of the satellite images. This will allow for more accurate predictions of marine currents, aiding divers, search and rescue operations and coastal monitoring.

Figure 2: Techniques such as data fusion and super resolution can allow oceanographers to improve the accuracy of marine current models in coastal areas.



Source: University of Malta (2018)

Figure 3: An example illustrating key steps in identifying patterns in satellite imagery



Source: MCAST (2018)

PIXAM

Pixels and More (PIXAM) is a research project coordinated by the Malta College of Arts, Science and Technology (MCAST) in collaboration with the Ministry for the Environment, Sustainable Development and Climate Change (MESDC) which will make use of datasets supplied by Copernicus Sentinel 2 satellites. The project, led by Mr Steve Zerafa (MCAST), exploits the fact that Sentinel satellites provide full coverage of the Maltese islands every few days in 13 multispectral bands. The research seeks to develop deep learning algorithms that enhance the resolution and consistency of the satellite datasets. The algorithms to be developed shall help depict pixels patterns and aid in better understanding the dynamics of the local habitat, including mapping of selected crop patterns and soil moisture across agricultural fields and valleys.

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CHAPTER 10

Repository of best practices on industry-academia collaboration to creating and disseminating knowledge in the spatial and GI domains

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Despina Kallidromitou

Introduction

There is a need to align the geospatial education and training offered by European universities with the requirement of the private and public sector to have access to a well-trained Geographic Information workforce. Over the past decades the collaboration between academia and the private and public sector gained importance in research as well as education. However, a more intense collaboration and more innovative methods are necessary to cope with the challenges of the fast-evolving technological developments in the geospatial and ICT fields. In the context of the giCASES/Erasmus+, a case-based and collaborative learning method has been designed based on the concept of co-creation of knowledge. Six case studies have been identified and described to test the approach. The case studies have been analysed and modelled with focus on three collaborative learning patterns. This paper describes the approach, the identified case studies, and the collaborative learning patterns. In ongoing and future work, the different patterns served as use cases for the deployment of a collaborative learning platform and for testing the co-creation of knowledge. The paper bases itself on the outputs/talks/speeches emanating from conferences and seminars: https://www.eracon.info/, http://www.gicases.eu/, https://agile-online.org/

Theorical Issues

The specific objective of the giCASES has been to improve the quality and relevance of GI courses provided by the University members of the consortium, to facilitate the growth of new knowledge-sharing processes and tools between enterprises and universities and to improve the management of knowledge by the partners. The overall approach to address this objective has been to develop learning material and processes based on case-based learning. In the giCASES approach, enterprises and academia collaborate both when creating learning material based on real cases and during the courses (through a collaborative platform). The new learning material and collaborative teaching has been tested in university settings. Questions related to processes for creation of knowledge and knowledge repositories have been placed at a strategic level, also within the enterprises. The project results are provided under open licenses. To optimize the spread and usage of the results, dissemination actions specifically address external universities adhering to the open learning paradigm.

Relative Thematic Areas

At least five thematic areas are directly correlated with giCASES. Firstly, giCASES is project -based. That means that experiences are gained through project management and implementation and Societal benefits are gained from National, EU and International projects. giCASES covers thematic areas related to social aspect and also futurism and prediction. Spatial technologies, as GI and its real-life application are correlated to giCASES. Emergent realities such as Virtuality, Augmented Reality & Innovation are related to giCASES and its implementation.

Methodology & Analysis of Case Studies

To test and validate the proposed case-based learning approach, 6 case studies (CS) were defined which tackle specific real-world problems and have well-defined scopes, learning outcomes, results, time frames, actors, and corresponding roles. They are:

1. Use of indoor GIS in health care

The objective of this CS has been to introduce a group of 4-5 students to the topic of GIS-based indoor Location Based Services (LBS) and engage them in the development of a real application in a context of interaction between a university and a SME company. The development of this CS has been based on a variety of learning methods, which encompasses traditional theoretical lectures and practical hands-on tutorials and teamwork sessions.

Training/education

The CS is developed within the course “Geographic Information Systems (GIS)” which includes Location Based Services (LBS), Indoor LBS principles and OGC IndoorGML standard, offered at Politecnico di Milano.

CS 1 provides a first approach of a joint teaching effort between university and industry. Students overpass the traditional boundaries of a university course, tackle a real case study and benefit from a practical teamwork experience with industry indoor GIS technologies.

At the end students can develop a complete mobile, web or desktop application based on indoor LBS.

2. Environmental analysis using cloud service systems

CS 2 addresses the use of new web technologies and GIS analysis to perform an integrated multi-criteria assessment for the evaluation of potential hazard to Site of Community Importance (SCI) areas caused by the exposure to agrochemicals and pesticide. For those analyses the next generation of technique has to use web tools and geo-processing more extensively. In fact, most data are now available via the web thought web services (OGC WxS or ArcGIS Server) and Linked Open Data protocols.

Training/education

This CS was developed and recognized as a Master thesis in International Master in Geographic Information Systems and Science at NOVA-IMS University in Lisbon. The courses include GIS & Science, Spatial Databases, GIS applications, Cartographic Sciences, Geostatistics and Databases & Geospatial Web Services. Students will obtain a new professional set of skills and expertise to integrate the GIS competences of Analyst using more web-GIS tool. Case Study 2 will enable students to solve problems related to the Environmental domain and to set-up data and to perform analysis on a new type of a platform, by starting to increase hazard analysis.

3. Location Enablement of e-Government

This CS aimed to set-up of a case-based and collaborative learning environment in the private company in the context of an existing internship course offered by KU Leuven. Students apply their already acquired knowledge and skills on GIS, SDI and ICT to work in a mixed team with staff from the company to design, develop and/or test location enabled applications. By working together with experienced staff, the student learns new skills or apply what they have learned in a real-world context.

Training/education

CS3 is developed within the course "Geographic Information Systems (GIS) Internship. Programming and testing apps using the scrum methodology, Integration of INSPIRE components and use of API's, Geomajas and other Open-Source environments included in the learning contents.

Students work with company staff enhancing teamwork. They learn to consolidate the theoretical knowledge and basic technical skills regarding GI and GIS development and usage, to analyze and describe e-Government processes in which location information

& services will be embedded. They also gain a thorough experience in designing and developing applications for making spatial data available, for decision making and e-Government. Thinking from the user perspective in the design phase of such applications and analyzing user requirements are both benefits gained from the learning process. Students exercise social skills, develop attitudes such as flexibility, the ability to organize, to be critical as well as to be geared towards results.

4. Integrated management of the underground

The CS4 has dual scope: the asset management of utility networks and the sharing of utility network data. Infrastructure asset management is the combination of management, financial, economic, engineering, and other practices applied to physical assets with the objective of providing the required level of service in the most cost-effective manner. Data sharing refers to the technologies, procedures, standards and regulations to be applied when sharing data with external parties.

Training/education

This CS was implemented as an elective course included in an International M.Sc in applied Geoinformatics offered by University of Salzburg. INSPIRE Data Specification & Network Services, Metadata and Data validation for INSPIRE are included in the learning contents.

CS 4 enables students to become acquainted with the main problems related to utility networks and asset management and to have knowledge about the concepts and terms used in data sharing, data harmonization and service provision and also about the concepts and terms used in project management and in the management of electricity networks and water supply systems. Students are able to publish utility network data through standardised network services and to specify different requirements on asset management system for utility network, for instance risk models and cost and revenue models. Finally, they understand the complexity, objectives and benefits of modern software for management of utility network.

5. Harmonizing data flows in energy saving EU policies

The objective of this CS is to engage a group of 4-5 students in the development of an application focused on one or more specific aspects of a data flow in support of one of the energy policies. The implementation relies on the concepts, principles and technicalities of the EU INSPIRE Directive, and are based on a preliminary analysis of the current EU policies on energy efficiency.

Training/education

This CS has been developed within the course "Geographic Information Systems (GIS)" consists of Energy Saving/Efficiency Policies, data harmonization and interoperability according to INSPIRE and open-source geospatial software and open standards.

At the end of CS5 students acquire a deep understanding of the issues related to spatial data harmonisation workflows contained in the different phases of the energy efficiency policies lifecycle and how effectively apply IT and GIS technologies in this field. Students need not just to use the concepts/tools learned during the course but exploit their personal knowledge and skills to find solutions to the problems encountered. This experience enhances the student's curricula and fosters their employability, as it prepares them to work in the industry sector related to energy efficiency as professionals with geospatial skills.

6. GIS Applications in Forestry

The scope of this CS is (by creating a well-structured graduate / postgraduate course) to introduce GIS tools to be used in forest management, and to provide novel data processing, spatial and multi-objective methods. The general aim is to provide the students with a firm theoretical foundation and understanding of forest management, including the social and environmental parameters and the ability to apply theory in practice, through the lab sessions.

Training/education

The Case Study implemented within Forestry MSc Programme contains as learning material Forestry GIS database, forest Mapping & data collection and LIDAR based timber volume estimation. It also includes Climate change, multi-objective forest management, Forest Risk Mapping, Forest Fire Monitoring and Forest Fire Simulation.

The completion of the course is accompanied by the capability of the students to prepare thematic maps for decision makers, to develop a critical awareness of forest management from a multidisciplinary perspective, to use complex tools and methods serving at the real-world fire cases and finally to be able to conduct geospatial analysis and simulation of forest fire events.

Figure 1: The six case studies of giCASES

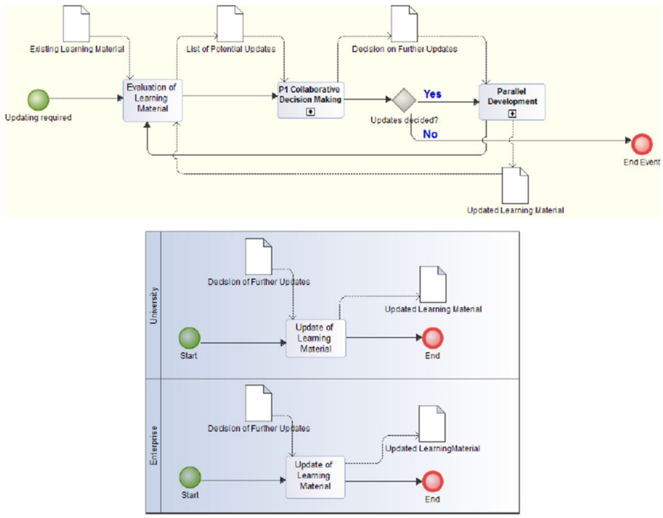
In the six case studies open data (over all OpenStreetMap), OGC standards and services (such as QGIS, GRASS GIS, GeoServer, PostGIS, OpenLayers, and Leaflet) are used. This shows how open-source solutions are widely used not just as GI teaching tools at the universities, but also to develop powerful business products at the companies.

All case studies are different from each other, but the processes used to co-create knowledge may have many characteristics in common. The common characteristics of the collaborative processes used in the various cases studies to co-create knowledge have been modelled through a high-level description (abstraction), defined as patterns of co-creation or "use cases", i.e., the abstraction of a context-specific process of collaboration which can be then realized within one or multiple case studies. The process patterns of case based learning and co-creation of knowledge have been classified according to their degree of collaboration and their type of output. Four collaboration patterns were identified and described using BPMN (Business Process Model and Notation) diagrams.

1. Shared development of learning material

In this process, co-creation of knowledge between the academic and industry partners happens through the development of learning material. Thus, it consists of a "shared process" whose output is learning material. The representation of this process through the BPMN notation is shown in Figure 2.

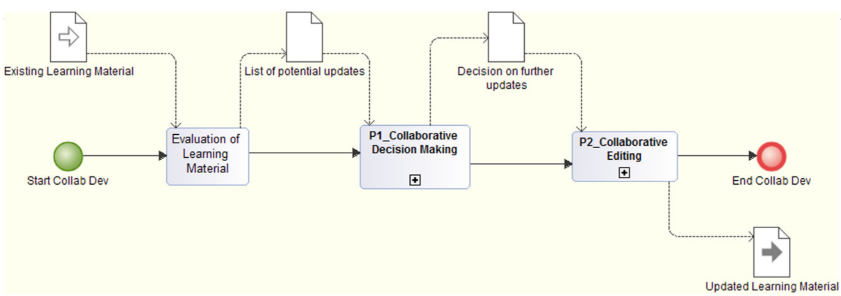
Figure 2: BPMN diagrams for use case 1: Shared Development of Learning Material (top) and Parallel Development (bottom)



2. Collaborative development of learning material

In this process co-creation of knowledge between the academic and industry partners happens again through the development of learning material. However, it now consists of a "collaborative process" whose output is learning material. The representation of this process through the BPMN notation is shown in Figure 3.

Figure 3: BPMN diagrams for use case 2: Collaborative Development of Learning Material



3. Shared provision of training

In this process co-creation of knowledge between the academic and industry partners happens through the provision of training to the students. Thus, it consists of a "shared process" whose output is training/education. The representation of this process through the BPMN notation is shown in Figure 4.

4. Internships

In this process co-creation of knowledge between the academic and industry partners happens through the internship of one or multiple students at the company. Thus, it consists of a "collaborative process" having its own specific results (such as a software or an app, a dataset, a Web service, a report, etc.). The representation of this process through the BPMN notation is shown in Figure 5. Results of giCASES are:

- Creation of a repository of best practices on industry-academia cooperation to create and share knowledge in the GI domain
- Definition of the focus, scope, and requirements of the case studies
- Specification of innovative collaboration methods, with best practices on different methods and validation of these methods in different settings
- Definition of process, tools, and methodologies for co-creation of knowledge
- Definition of technical specifications for the setup of a collaboration tool (collaborative platform) and implementation of the technical infrastructure
- A set of case studies adopted for case based learning and related learning material
- Collaborative platform to make results available to other stakeholders under open licenses and to attract more content providers / stakeholders to contribute to the growth of the content base.

Figure 4: BPMN diagrams for use case 3: Shared Provision of Training (top) and Shared Training (bottom)

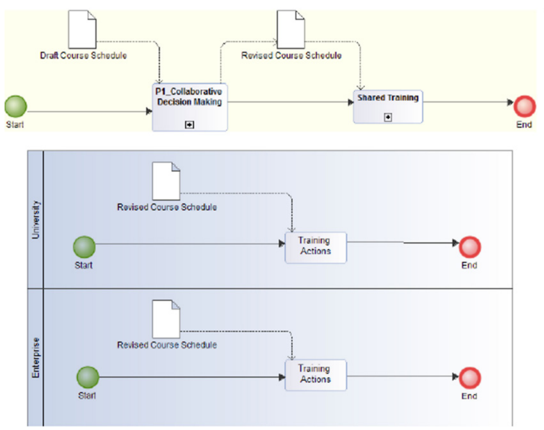
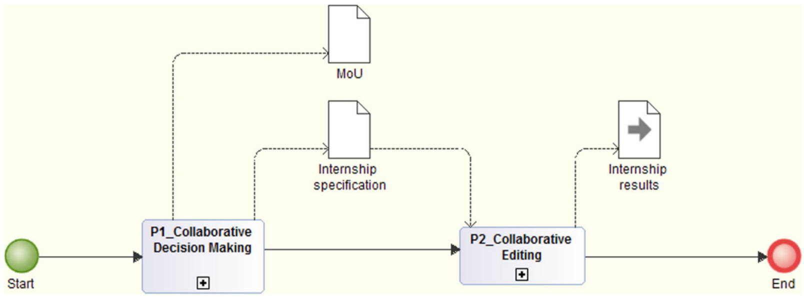


Figure 5 – BPMN diagram for use case 3: Internship



Note

This chapter was drafted in 2018 as part of the collaboration between the authors and the Maltese SIntegraM project. The indicated data and datasets are updated over time and can be reviewed through the relative links. This Chapter forms part of the giCASES project and is aimed at describing the project from a spatial analytical perspective. All rights remain those of the programme.

Results and Conclusions

Since the learning offer should respond to market needs timely, it is no longer possible to develop curricula or, in general, learning paths, either in formal or informal settings, based on identified needs, since those needs will have changed in the same timespan needed by HEIs to design and put in place the curricula. That is why the involvement of businesses in instructional design must become the standard way to match labour market needs, and the case-based approach proposed by giCASES, together with the collaborative learning paradigm to foster co-creation of knowledge, are considered as the elective tools to achieve such an ambitious scope.

This collaboration model also addresses the acquisition of transversal and soft skills, which are nowadays recognized as labor market-relevant skills to boost employability and competitiveness of the workforce, in line with the communication by the European Commission "A new skills agenda for Europe" (European Commission, 2016). Thanks to the open access policy adopted by giCASES and the replicability of the developed methodology, other stakeholders are expected to join the Alliance and to adopt its case-based approach as a university-business cooperation model, generating a direct or indirect effect on actors, structures, sectors, or systems at the EU level.

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Pivot III

Thematic: Environmental, Social and Development Planning Domains

Terrestrial Image: AI Generated Art
AI Art App - SF

CHAPTER 11

Assessing ecosystem services for evidence-based nature-based solutions interventions

Mario V. Balzan

Introduction

During recent years, Europe has seen a surge of research and policy initiatives on ecosystem services (Maes & Jacobs, 2017), the latter being defined as the direct and indirect contributions of ecosystems to human well-being (De Groot et al., 2010). Ecosystem services research connects ecology with human-wellbeing and economy by analysing the links between ecosystems and the benefits people receive from nature (Potschin & Haines-Young 2016). The contributions of ecosystems to the attainment of social and economic policy objectives have been recognised by the European Union policy. The EU Biodiversity Strategy to 2020 sets important targets for the development of knowledge about ecosystems, their services and values in the national territory of member states and the integration of these values into accounting and reporting systems at EU and national level. Building on this, the EU Green Infrastructure Strategy recognises the pivotal contributions of ecosystems for more systematic economic solutions (Maes & Jacobs 2017).

The important role played by green infrastructure for sustainable economic growth is also recognised by Malta's National Green Economy Strategy (2015). Green infrastructure, defined as a strategically planned network of natural and semi-natural areas that is multifunctional, providing multiple services and benefits whilst also protecting biodiversity in rural and urban areas. The multifunctionality of green infrastructure is also, indirectly, recognised by Malta's Strategic Plan for Environment and Development (SPED) which includes in its objectives the protection of existing recreational areas to improve social cohesion and human health, whilst supporting the strengthening of the existing ecological network and recognising the important contribution of urban green spaces. Malta's National Biodiversity Strategy and Action Plan (NPSAP) 2012-2020 also recognises the important value of ecosystems and their services and aims to develop the existing thematic knowledge base (Target 18), integrate this in national policies as well as decision-making and planning processes (Target 2), and restore at least 15% of degraded ecosystems and for the essential services provided vulnerable ecosystems to be safeguarded (Target 13).

The operationalisation of the ecosystem service concept is a key objective for researchers and practitioners working at the interface of science and policy. In its most rudimentary sense, the idea is to mainstream ecosystem services into decision-making because there are a range of nature-based solutions to societal challenges (Potschin-Young et al., 2016). However, several challenges to the implementation and uptake of the ecosystem services concept exist, and the mapping and assessing of ecosystems and their services has been implemented with varying success across the EU member states (Kopperoinen, Varumo, & Maes, 2018). The most successful EU countries having implemented nation-wide ecosystem service assessment and developed methodologies and tools for their use in decision-making. The assessment and mapping of ecosystem services, and their integration in decision-making, presents several challenges which include the lack of an accepted and coherent approach and frameworks and the limited availability of empirical data (Burkhard, Maes, et al., 2018). The implementation of the ecosystem assessments in Malta (e.g. as reviewed by Mallia and Balzan, 2015), is associated with a number of challenges, which include the availability of biodiversity and ecosystem services spatial data that cover the territory at adequate resolutions (Balzan, Caruana, & Zammit, 2018).

This appears to be a common situation for small island states across the globe, as demonstrated by a recent review about small island ecosystem services which indicates that studies that carried out a biophysical quantification of ecosystem services, investigated their spatial variation, arising synergies and trade-offs, or assessed the socio-cultural and economic value of island ecosystem services are rather limited. On the contrary, most of the studies dealt with the management of pressures, and externalities and trade-offs associated with the use of ecosystems and their services (Balzan, 2018; Balzan, Potschin, & Haines-Young, 2018). This is congruent with the view that sees nature as a resource to be exploited for temporary economic successes (Maes & Jacobs, 2017).

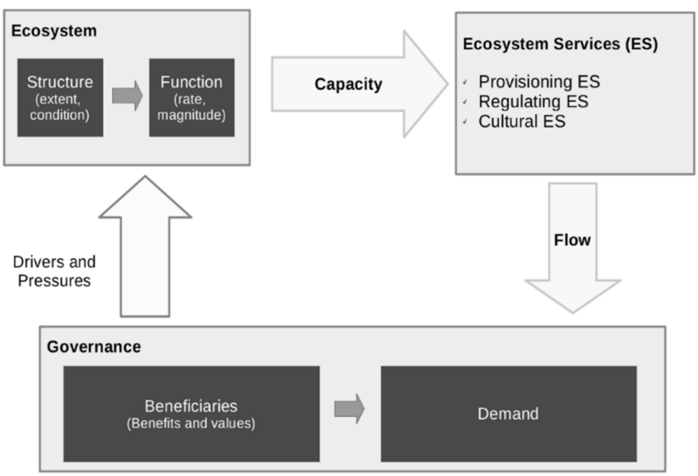
The assessment of ecosystem services requires a complete understanding of the flow of services from ecosystems to society, and consequently the use of different indicators that are based on meaningful science is required for an effective implementation of the ecosystem services concept (Potschin & Haines-Young, 2016; Villamagna, Angermeier, & Bennett, 2013). This contribution provides an overview of the recent research activities mapping and assessing ecosystem services at a national scale, and briefly discusses the implications for decision-making.

Conceptual Framework

The ecosystem service framework adopted in this work (Figure 1), builds on existing widely used frameworks (Potschin & Haines-Young, 2016; Villamagna et al., 2013), and distinguishes between different components along the ecosystem services delivery chain (Table 1). To understand the relationship between people and ecosystems, we need to identify both the functional characteristics of ecosystems that give rise to services and the benefits and values which arise from these (Potschin & Haines-Young, 2016). Assessments carried out distinguish between ecosystem services capacity and flow, with the capacity being defined as the potential of ecosystems to provide service, while the flow refers to the actual production and mobilisation of the service. The ecosystem service demand depends on the beneficiaries' preferences for specific ecosystem service attributes (Potschin-Young, Burkhard, Czúcz, & Santos-Martín, 2018). In a final 'societal input' feedback loop, through decision-making, societies manage drivers of change impacting indirectly on ecosystem through the action of pressures (Nassl & Löffler, 2015).

The implementation of ecosystem-based approaches and measures which use nature's multiple services as 'nature-based solutions' to societal challenges is considered as being part of the governance regime within this framework as it effectively impacts on the drivers and pressures acting on ecosystems whilst promoting the provision of ecosystem services and improving resilience. Nature-based solutions operationalise the concept of the ecosystem services in real-world situations (Faivre, Fritz, Freitas, de Boissezon, & Vandewoestijne, 2017). Nature-based solutions are considered as being part of the green infrastructure since they use biodiversity and ecosystem services as part of an overall adaptation strategy.

Figure 1: Conceptual framework for the assessment and mapping of ecosystem services to develop the evidence base for nature-based solutions interventions.



Adapted from: Balzan et al., (2018a)

Table 1 – Defining the key components of an ecosystem services conceptual framework

Term	Definition
Beneficiaries	A person or group whose well-being is changed in a positive way by an ecosystem service conservation.
Driver	Any natural or human-induced factor that indirectly causes a change in an ecosystem.
Ecosystem condition	The physical, chemical and biological condition or quality of an ecosystem at a particular point in time.
Ecosystem function	The subset of the interactions between biophysical structures, biodiversity and ecosystem processes that underpin the capacity of an ecosystem to provide ecosystem services.
Ecosystem service	The direct and indirect contributions of ecosystems to human well-being.
Ecosystem service capacity	The ability of an ecosystem to generate a specific ecosystem service in a sustainable way.
Ecosystem service demand	The expression of the beneficiaries' preferences for specific ecosystem service attributes, such as biophysical characteristics, location and timing of availability, and associated opportunity costs of use.
Ecosystem service flow	The actual production or use of the ecosystem service in a specific area and time
Ecosystem structure	A static characteristic of an ecosystem that is measured as a stock or volume of material or energy, or the composition and distribution of biophysical elements.
Governance	The process of formulating decisions and guiding the behaviour of humans, groups and organisations in formally, often hierarchically organised decision-making systems or in networks that cross decision-making levels & sector boundaries.
Green infrastructure	A strategically planned network of natural and semi-natural areas with other environmental features designed & managed to deliver a wide range of ecosystem services. It incorporates green or blue spaces and other physical features in terrestrial, coastal and marine areas. On land, green infrastructure is present in rural and urban settings.
Nature-based solutions	Living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits.
Pressure	Human induced process that directly alter the condition of ecosystems.

(adapted from Potschin-Young et al., 2018)

Mapping and Assessing Ecoystem Services

Recent EU-funded research has permitted the development of flexible ecosystem services mapping and assessment methodologies, and their testing in representative thematic and biome-oriented case-studies. This is expected to promote local ecosystem service assessments required for spatial planning, agriculture, climate, water and biodiversity policy (Burkhard, Maes, et al., 2018). The EU-funded Horizon 2020 project ESMERALDA (Enhancing ecosystem services mapping for policy and decision making) has developed a 7-step mapping and assessment of ecosystem services (MAES) implementation plan that:

- identifies questions that stakeholders have and which may be answered by the MAES;
- identifies relevant stakeholders, for instance from science, policy or society, that are in a position to deal with these question;
- establishes a network involving the relevant stakeholders;
- implements the mapping and assessment process according to the available knowledge and data aspects;
- implements case-studies to test the MAES approaches;
- develops a user-oriented dissemination and communication of ecosystem service mapping and assessment outcomes is implemented; and
- integrates ecosystem services in decision-making in policy, business and practice (Burkhard, Sapundzhieva, et al., 2018).

A case-study has been carried out to map and assess ecosystem services in the Maltese Islands and to test assessment methodologies (Balzan, Caruana, et al., 2018). This study consists of a first assessment of the capacity and flow of ecosystem services in the Maltese Islands and has been carried out in order to analyse the spatial variation of ecosystem services, identify service hotspots and explore the impact of policies and developments on the ecosystems' capacity to provide key ecosystem services. The assessment builds on an analysis of the status of active research and policy initiatives, prerequisites and needs at start of the project. This review identified the ecosystems covered in the country, listed some of most relevant ecosystem services, and identified stakeholders that may be involved in the mapping and assessment process (Mallia & Balzan, 2015).

The mapping and assessment of ecosystem services is largely dependent on the availability of land cover land use (LULC) datasets at adequate resolutions and of data about the condition of ecosystems that is based on information about drivers, pressures and the impacts on structure and function of ecosystems. Balzan et al. (2018a) identified spatial data availability about ecosystems and their condition as being an important limitation for the mapping and assessment of ecosystem services. Similar observations have been made elsewhere suggesting that there is often a lack of local-scale data for the implementation of ecosystem service assessments for decision-making (Burkhard, Kroll, Nedkov, & Müller, 2012).

During the implemented case-study, a LULC map was created using Sentinel 2 satellite images provided by Copernicus (Drusch et al., 2012). Following the adoption of the conceptual framework (Figure 1), several indicators that may be used to assess key ecosystem services in the Maltese Islands were identified (Table 2). An ecosystem service indicator has been defined as information about the characteristics and trends of ecosystem services, which may be used by policymakers to understand the condition, trends and rate of change in ecosystem services (Layke, Mapendembe, Brown, Walpole, & Winn, 2012; Maes et al., 2016). Based on the adopted framework, two types of ecosystem service indicators have been used: indicators that communicate the capacity of an ecosystem to provide a service and those that communicate the flow, or actual provision, of an ecosystem service.

The case-study assessed the role of various terrestrial ecosystems in the delivery of multiple ecosystem services. Results demonstrate that semi-natural and agroecosystems make the backbone of the green infrastructure network in the Maltese Islands, and that these are important for the delivery of various ecosystem services leading to improved human well-being in Malta. In contrast, predominantly urban areas were characterised with a low capacity of ecosystems to provide services resulting in societal benefits affecting human well-being and indicating that ecosystem service delivery in the landscapes of Malta is determined by land use intensity (Balzan, Caruana, et al., 2018).

The availability of green infrastructure and the contribution of this to the delivery of ecosystem services in each locality in the Maltese Islands was analysed by Balzan (2017). In this work, the area of green infrastructure in each local council was calculated from a generated land use land cover (LULC) map. Given that green infrastructure is considered as being a network of natural and semi-natural areas that provides a wide range of ecosystem services (EC, 2013), the cover of ecosystems contributing to the delivery of multiple ES was summed up for each locality. Ecosystem service capacity was strongly associated with the availability of green infrastructure, whilst urban areas associated with higher population densities had the lowest green infrastructure cover and ecosystem services capacity (Figure 2). In contrast, higher ecosystem service flow rates were recorded in ecosystems located in urban environments, which may be associated with higher ecosystem service demands in cities. Balzan et al. (2018a) recorded the highest NO2 removal flux in woodland areas located in urban environments. Similarly, in a recent work assessing and mapping recreational ecosystem services using georeferenced data from the GPS-outdoor game Geocaching, the highest cache density was recorded in woodland and the urban green and leisure area category. The latter was also the most likely to be considered as a favourite point by those participating in this recreational game (geocachers). The results also indicate that the wider landscape impacts on ecosystem service flows, and the number of favourite points was positively associated with areas of high landscape value (Balzan & Debono, 2018).

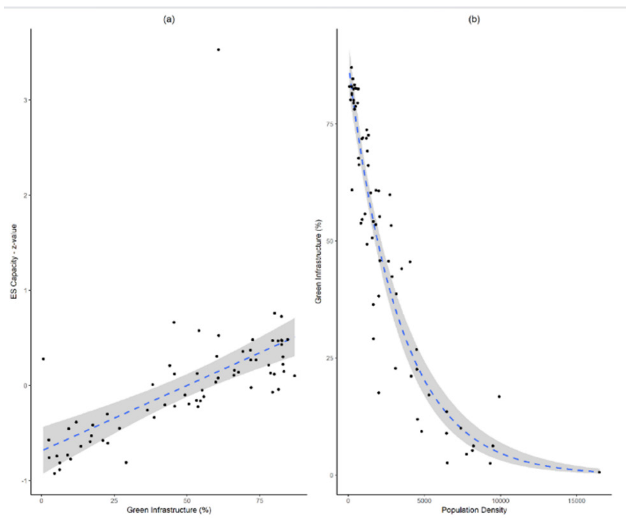
Table 2 - Indicators used for the assessment and mapping of ecosystem services and based on previous contributions

Ecosystem Service (CICES 4.3)	Indicator	Capacity/Flow
Cultivated crops	Downscaled crop production (ton/ Km^2)	Capacity/Flow
Reared animals and their outputs	Beekeepers' Habitat Preference (Frequency of responses)	Capacity
Reared animals and their outputs	Number of hives/Km^2	Flow
Materials from plants, algae and animals for agricultural use	Rainfed agricultural land (Fodder production potential)	Capacity
Materials from plants, algae and animals for agricultural use	Livestock (number of Cattle, Sheep, Goats)/Km^2	Flow
Pollination and seed dispersal	Pollinator visitation probability	Capacity
Pollination and seed dispersal	Crop pollinator dependency	Flow
Dilution by atmosphere, freshwater and marine ecosystems	NO_2 deposition velocity (mm/s)	Capacity
Dilution by atmosphere, freshwater and marine ecosystems	NO_2 removal flux (ton/ha/year)	Flow
Physical use of land- /seascapes in different environmental settings	Number of habitats of community importance	Capacity
Physical use of land- /seascapes in different environmental settings	Visitation to sites and urban green areas for recreational activities	Flow

Physical use of land- /seascapes in different environmental settings	Geocaching point location	Capacity
Physical use of land- /seascapes in different environmental settings	Number of geocache quests/ favourites	Flow
Aesthetic	Preference Assessment with locals (Frequency of responses)	Flow

Source: Balzan, 2018

Figure 2: (a) Assessing the relationship between green infrastructure cover (GI) in each local council and average ES capacity and (b) population density.



Source: Balzan (2017)

Developing Evidence-Based Nature-Based Solutions Interventions

The described results demonstrate that the identified ecosystems contribute to the delivery of multiple ecosystem services within the study area. Other studies have similarly recorded positive associations between green infrastructure and ecosystem service delivery, for example, through improved food security (Dennis & James, 2016), the removal of air pollution and the provision of space for recreation (Baró et al., 2016), local climate regulation (Zardo, Geneletti, Pérez-Soba, & Van Eupen, 2017) and improved mental health (Alcock, White, Wheeler, Fleming, & Depledge, 2014; van den Berg et al., 2015). These results provide evidence that land use planning that implements and promotes the use of nature-based solutions whilst developing green infrastructure can significantly contribute to maintain biodiversity within landscapes whilst generating ecosystem services leading to benefits to human well-being.

Nature-based solutions are implemented to address societal challenges, and therefore selected methods and approaches will depend on local needs (Raymond et al., 2017). Assessments presented here provide first evidence of the distribution of green infrastructure, and the benefits arising from the delivery of various ecosystem services. It may be complemented by the development of indicators for the assessment of ecosystem service demand, which can be compared with ecosystem service flow indicators to identify whether the demand for ecosystem services is satisfied (Baró et al., 2016). This would provide key information about the unsatisfied demand for ecosystem services leading to identified local challenges, for example because of high air pollution levels, surface water runoff generation due to soil sealing or limited availability of green spaces for the recreation of residents. Nature-based solutions are implemented to provide solutions to such challenges and therefore benefit from ecosystem service assessment and maps which build the scientific evidence about the needs for the implementation of nature-based solutions. In addition, challenges requiring nature-based solutions interventions impact on socio-ecological systems, are therefore often complex and multidimensional and, would therefore benefit from transdisciplinary and participatory approaches which offer informed societal choices. The alternative is the uninformed implementation of nature-based solutions without measures of their effectiveness in addressing societal challenges.

The identification of nature-based solutions is normally based on an assessment of its potential to lead to environmental, social and economic benefits, through ecosystem services delivery. Consequently, indicators are chosen for the monitoring of the long-term impact of nature-based solutions at adequate geographical and ecological scales (Cohen-Shacham, Walters, Janzen, & Maginnis, 2016). This is an opportunity for practitioners, landscape and urban planners, and decision-makers to promote the development of the knowledge base about the links between green infrastructure and human well-being, and to guide ongoing and planned afforestation and restoration initiatives and the inclusion of other nature-based solutions, such as green walls and roofs, sustainable urban drainage systems and green spaces, in urban areas for more effective implementation.

Conclusion

This paper has provided an overview of the recent work mapping and assessing ecosystem services in Malta and the implications for decision-making for the implementation nature-based solutions to address societal challenges. Gradients in green infrastructure availability and in the delivery of ecosystem services have been identified. The mapping and assessment of ecosystem services provide information about the links and balances between the capacity and flow of ecosystem services and the arising benefits to human well-being. These play an important role in the development of the evidence basis for the identification of nature-based solutions leading to societal, environmental and economic impacts and which address societal challenges.

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CHAPTER 12

Need of a Collections Management System and solid metadata structuring for digitised Cultural Heritage

Tony Cassar and Andrew Pace

Introduction

Heritage Malta, the national agency for museums, conservation and cultural heritage, was established in 2002 replacing the former Museums Department. Initially, Heritage Malta was entrusted with the management of museums, sites and their collections; however, in 2005, the agency's responsibilities increased when it took over the former Malta Centre for Restoration, to become the national agency responsible for conservation. Through its formation, Heritage Malta inherited a considerable collection of artefacts alongside a mass of documentation about them in various non digital formats. Previous attempts to establish digital methods to bring together these collections of data over the past decade have partially solved the issues they were set out to accomplish, but a comprehensive system has not yet been implemented that successfully achieves this in totality. The need for an enterprise information system to gather all collections in one data space was considered for years. In 2022, a new collections management system (CMS) was introduced which will become this repository, consolidating all data about the national collection into one centralised system. Crucially, elements of this system will be accessible to the public through a web portal. It will therefore provide both a backend platform for cataloguing objects, tracking their movement, incorporating conservation reports and other key administrative activities, and a parallel access portal to share the National Collection administered by Heritage Malta online.

The CMS would see the creation of comprehensive digital records for every single artefact in the collection. Central to the successful operation of this platform is good metadata, arranged in standard formats, accessible to the right people. This chapter reports on the work of Heritage Malta's Digitisation Department to implement this system over the past eighteen months and details the benefits it will provide to the agency and to the public. Heritage Malta strongly believes that digitising cultural heritage does not end with capturing digital representations of cultural artefacts, but rather that digitisation incorporates a broad spectrum of activities that involve collection documentation, workflow consolidation, creative and educational interpretation, and technical procedures.

Heritage Malta

Heritage Malta manages 90 museums, landmarks, national monuments and underwater sites that represent the cultural heritage of the Maltese islands. Established in 2002 through the Cultural Heritage Act, Heritage Malta replaced the former Museums Department which had existed since 1903 with a more comprehensive structure. In 2005, the agency incorporated the Conservation Department, enabling in-house expertise for the conservation and restoration of artefacts within our care. To this, the Diagnostic Science Laboratories (DSL) and Digitisation Department have been added in more recent years to further enhance the scientific and technical capabilities of the agency.

Encompassing nearly 120 years of acquisitions and 7000 years of history, Heritage Malta's collections are significant in their range, depth and importance. However, the public can only easily access a very small portion of these collections through Heritage Malta's permanent and temporary museum exhibitions. As with all major museums worldwide, most of our artefacts are kept in the reserve collections of each museum, inaccessible except by request. Although annual reports containing lists of acquisitions and additions may be viewed by the public through the agency's website, this does little to instill within the public the scale of these collections or the significance of the objects to a collective shared heritage. As a majority public funded agency, Heritage Malta believes that our future lies in providing access to the 95% of collection objects that remain hidden from public view.

In this regard, the Digitisation Department is leading a concerted effort across several key Heritage Malta departments to improve access to the national collection. Enabled through an EEA Norway Grant of 1.7 million Euros, shared with the Malta Maritime Museum project (Heritage Malta, 2022a), the resources of the department have been greatly expanded to encompass documentary photography (DSLR, flatbed, overhead archival scanning, RTI) and 3D scanning (Lidar and photogrammetry, including drone photogrammetry), and museum interpretation methodologies through video, virtual reality, augmented reality, holography and game design (Heritage Malta, 2022b). A key aspect of this drive toward accessibility is implementing a collections management system that consolidates the catalogues of Heritage Malta museums and sites, into which the media assets generated by the Digitisation Department can be attached and accessed.

The case for a CMS

Following an international call for suppliers, an off the shelf collections management system, Gallery Systems TMS, was purchased, implemented and tested in phases throughout 2022. Following setup and testing, this CMS is expected to go live for staff members in early 2023, with a limited public roll out later that year. Through this platform, collection inventories, catalogue data, conservation records and media assets can be connected and accessed through a single interface. Most importantly, metadata can be consolidated and made consistent through TMS, effecting a significant change from the distributed documentation that exists to date. Although the work required to consolidate this data will be an ongoing challenge for several years to come, the benefits of the system to staff at Heritage Malta are obvious. The Digitisation Department has been in touch with two other Gallery Systems users, Tate and National Gallery, to learn how they have customised their own installations, and have learned a great deal about how to build a usable system for staff and for public access. Through these fact-finding missions, consulting international guidelines on procedures and standards, and undertaking an internal implementation-research phase across Heritage Malta departments during 2021 and 2022, several key concerns about the migration of data and workflows were identified that can be solved directly through TMS.

Among these concerns, the most significant issues faced relating to metadata are: inconsistent inventories of collection objects (including the application of unique object identifiers), the distributed nature of catalogue records and how to access and modify them, a lack of object movement tracking, a consolidated media store and search facility for digital assets (whether these are collection objects or digital representations of them generated by the Digitisation Department), the tracking of collection objects used in exhibitions, and the public availability of all of the above (also in relation to accessibility and security permissions). As implied here, whilst the Digitisation Department is primarily concerned with digitising cultural heritage assets for interpretation – objects, monuments, sites, oral histories, exhibitions and events – the CMS would also enable the digitisation of agency-wide workflows for artefacts.

Tying together these workflows and metadata is Spectrum 5.1, an international collection management standard used by museums throughout the world (The Collections Trust, 2022). Administrative tasks and recommendations for workflows and policies relating to collections management are laid out in a range of 'procedures', which include, among others: Object Entry, Acquisition and Accessioning, Inventory, Cataloguing, Loans In, Valuation, Damage and Loss, Rights Management, Collections Review. TMS is fully compliant with Spectrum, meaning that it has the facility to capture and track all the information necessary to manage collections to these standards. By implementing our own installation of TMS in accordance with Spectrum standards, we can make the most of the tools afforded by the system and ensure that collections metadata can be futureproofed as much as possible.

To date the department has implemented three primary Spectrum procedures: Inventory, Cataloguing, and Location and Movement Control. At the Malta Maritime Museum (MMM) Heritage Malta's Collections Management Department is reviewing all the items in MMM's current inventory and establishing Object Numbers for each (as well as past numbers) and is ensuring accession records are present and prove rights ownership and provenance. In parallel to this, museum and Collections Management department staff are cataloguing these same objects, capturing core data (those fields that are essential for inventorying purposes) and extended data (fuller catalogue records).

All this data is currently being captured into a spreadsheet that is suitably arranged for migration to TMS. (Live entry into TMS will occur once the system has been fully tested and implemented.) Meanwhile, documentary photography of these objects is being undertaken by the Digitisation Department, which will be attached to those TMS records. Finally, location records have been created for MMM's reserve collection storage units, so that any time an object moves for cataloguing, digitisation, conservation, loan, exhibition, and so on, there is an administrative record that documents who moved it, why, and when, to establish full accountability for object handling. A selection of approximately 3,000 objects from the Malta Maritime Museum that have been processed through these Spectrum Procedures is expected to be made live on TMS in early 2023.

As can be seen from this very brief overview of the work being undertaken at the Malta Maritime Museum (and to a lesser, phased extent at MUŻA, National Museum of Archaeology and Gozo Museum), the preservation of collection objects is being improved by comprehensively capturing more information in a central location. Preservation is thus ensured not just through the protection and conservation of the physical object itself, but also through capturing a full metadata record about that object: how it is described, how it has been handled and used, tracking its provenance, and, of course, knowing exactly where that object is at any given time. As more Spectrum procedures are incorporated into workflows over the years, more complete Object Entry, Insurance, Rights Management and Auditing procedures (among others) will be added to more comprehensively maintain and access important metadata about the national collection.

However, preservation is only one important aspect of Heritage Malta's remit. The very first sentence of the agency's mission statement reads: "The mission of Heritage Malta is to safeguard and render accessible the cultural heritage entrusted to it...". Access must be considered on an equal footing with preservation. As alluded to above, whilst Heritage Malta makes every effort to rotate items from the reserve collections into museums and exhibitions, a significant portion of the total collection objects remain out of sight without a simple way for the public to discover these holdings. To solve this, TMS incorporates a web publishing module, eMuseum, that publishes records to a public portal. Here, users can search, discover and view images of collection objects which have been approved by curators. Objects can be arranged in multiple ways by curators and by the public themselves; filtered by date, artist, manufacturer, all objects in a particular room within a museum, customisable favourites lists, etc. Furthermore, PDF downloads summarising collections and lists of objects can be automatically generated and customised as educational packages aimed at different age groups. The possibilities for interaction and discovery are endless. As more collections go online, some time-consuming tasks currently undertaken by curators – for example, searching photograph collections for a public research request, or searching catalogue data for works by a particular artist – can be undertaken online by the researcher themselves. This itself is a cost-saving bonus for Heritage Malta, whilst also giving the public agency to discover their own cultural heritage.

Next steps

TMS will be launched to some Heritage Malta departments in early 2023, whereby collection data will be uploaded by series. Spectrum procedures are more slowly being rolled out, largely invisibly through workflows and data capture inherent to TMS itself, but also by the Collections Management Unit undertaking collections reviews, such as the one described at Malta Maritime Museum. Public access to certain collections will be provided by mid-2023 through eMuseum, once a substantial number of objects are properly catalogued and photographed.

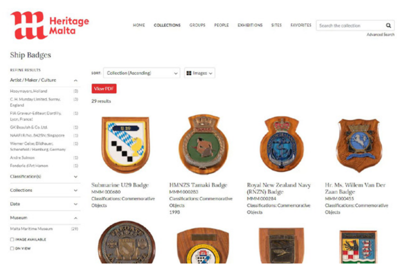
However, there are many other topics that the Digitisation Department is working on to augment the collections management system and enhance how they handle digital objects. One of these projects is to develop Creative Commons licenses for the non-commercial reuse of collection images via eMuseum, as well as to establish a payment gateway system to sell or license high resolution images of collection items. This will both streamline and clarify the way the public can access and use these collections, whilst also simplifying the means for us to acquire income from these assets, proving a level of sustainability towards running and maintaining a CMS. Key to this is clearly documenting the inherent rights of objects and applying suitable reuse policies for them, both of which are simplified via TMS. The department is also exploring how to incorporate Digital Twin project assets into eMuseum.

These assets are high quality 3D models of heritage sites and exhibitions that the public can interact with through a web or virtual interface. As with any other digital object, these assets require their metadata to be carefully captured. For example, each stone of a temple has a unique identifier. It would be very useful for the 3D models of each of these stones to be individually accessible to staff and researchers, with Geographic Information System (GIS) data embedded to understand their relationship to others. This metadata is not incompatible with more generic uses of a 3D model, but one must consider all potential use cases of assets and ensure that as much catalogue detail is captured as possible to increase the value of those records (Figures 1 to 4).

Figure 1: 2D scanning thousands of albums, glass plate negatives, photo negatives, diaries, documents, plans and other printed material

Source: Heritage Malta

Figure 2: The collections management system will make the National collection accessible both to users within the agency but also to the public in general

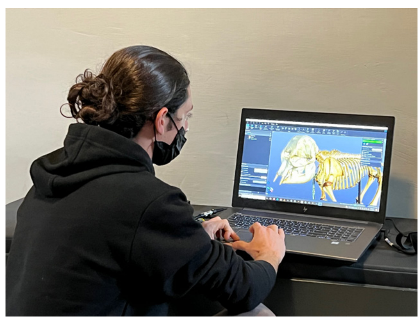


Source: Heritage Malta

Figure 3: Large area heritage sites can now be scanned and modeled using aerial photogrammetry

Source: Heritage Malta

Figure 4: Post processing a laser scan of a baby elephant to create a 3D model of the artifact



Source: Heritage Malta

In this regard, the Digitisation Department also engages with standards and international data aggregation projects, recognising that data sets are greatly enhanced in value when they can interact with other platforms. Firstly, the data itself must be formatted and presented to the web accordingly – enabled through platforms such as TMS and eMuseum – and secondly by being shared with aggregators, such as Europeana (Europeana, n.d.). In the first instance, one such project the department is undertaking is to establish core metadata requirements for documenting digitised cultural heritage that take the form of 3D objects and 360 models of objects and sites.

The department works extensively with this emerging field, following a European Commission white paper on the subject released in 2022 and attempting to implement its guidelines in Heritage Malta's own practices (European Commission, 2022). Secondly, the Agency is actively engaging with Europeana, and has been doing so (piece meal – due to lack of an enterprise CMS) for the past ten years, a portal through which digital cultural heritage assets are shared by national institutions for public access. Heritage Malta has been appointed as the national aggregator for Maltese collections that will be imported into Europeana. Heritage Malta has also been appointed on the Commission Expert Group on the Common European Data Space for Cultural Heritage and is also working on the European Collaborative Cloud for Cultural Heritage. By positioning ourselves actively with these projects, Heritage Malta can have a say on European-wide initiatives on data collection, aggregation and access.

Conclusion

The work of Heritage Malta's Digitisation Department reveals how digitising cultural heritage is a multi-faceted activity that extends well beyond simply documenting collection objects. TMS and eMuseum provide the mechanisms through which these collections and media assets are documented and shared; whilst workflows can also be digitised, as can auditing collections and administrative reporting. Capturing accurate metadata about objects, the processes that affect those objects, and organising and accessing that metadata through a comprehensive central portal are key to increasing the value of Malta's cultural heritage and ensuring that they are properly cared for – and proving that this is the case. As distributed ledger technology becomes increasingly important to track the provenance of cultural heritage, metadata is set to become an even more important facet of its work that proper attention must be paid to.

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CHAPTER 13

The significant YOU: community knowledge in an information society

Wendy Jo Mifsud

Introduction

The Digital Age in which we live has transformed the way people engage with each other. Space has evolved to incorporate the virtual environment created by digital technologies and people could interact in environments other than those which are physical. Towards the beginning of the digital revolution that characterises this age, an era of increased human connection facilitated by virtual environments was envisaged; coupled with enhanced social cohesiveness and the inclusion of marginalised communities. Such an inclusive society, it was thought, would bring about increased participation in governance processes and thus more legitimate stakeholder engagement in representation processes, amongst these, in spatial planning.

The currency of the Digital Age is the attainment of technical capital (Savage, 2013). Castells (1996, 2006) describes a society whereby technical capital is attained through creativity and innovation; aided by the ubiquitous use of personal digital technologies – a Network Society. The unfettered interaction that was however envisaged (Pickles, 1995) did not materialise. Rather, a networked individualism has occurred, in which family relations, patterns of consumption, modes of communication, methods of employment or the use of public space remain social activities but are nonetheless governed by individualist aspirations (Castells, 2002).

Technology being a means of currency, it is also a generator of inequalities since the means of acquisition and retention of the information is not egalitarian across all sectors of society. This is a consequence of the acquisition of technical capital being akin to that of the traditional concept of social capital, whereby acquisition of capital follows the trajectory set out by traditional power relationships related to material resources (van Dijk, 2013). These inherent inequalities in society cause exclusion from decision-making, resulting in biased representation processes which contradict democratic ideals.

Increasingly, grassroots organisations are gaining the social and technical capital required to demand participation in decision-making. Participatory mapping methods such as PGIS allow issues to be elucidated, analysed and visualised. When coupled with investment in human-resource capacity-building and adequate funding to support lengthy socio-spatial research, PGIS can bridge the divide between decision-maker and stakeholder by providing a means through which dialogue can flourish (Merrick 2003). Crucially, any initiative which enjoys statutory support has increased chances of directly influencing planning policy (Elwood and Ghose 2001), though this is challenge yet to be overcome in Malta.

Participatory GIS as a Research Tool

Haklay (2006) states that PGIS can be seen as "GIS for group problem solving" (p.25) in that it is a tool that prompts stakeholders to hold meaningful dialogue about places. The method is adept at increasing social capital since it allows participants to define which data is to be collected and how they prefer that this is done. This adaptability and participatory nature of the method has contributed to its use in a wide variety of scenarios to which it has been applied. In the quest for fostering social and technical capital, participatory mapping is based on the formation of a spatially grounded narrative which brings together a group of interested stakeholders towards the better understanding and analysis of an issue at hand.

A direct advantage observed in such PGIS initiatives is the gathering of in-depth local traditional knowledge, both spatial and otherwise. In fact, at variance to the use of 'Big Data' collated from social media databases, the methodology has evolved over time to be used particularly with groups of localised stakeholders. PGIS initiatives, therefore, are not organised with the aim of understanding trends in large data-sets pertaining to spatially widespread issues. It is best suited to understanding factors of social life pertaining to a defined place, such as cultural or political phenomenon in a city (Kahila-Tani et al., 2016).

These characteristics of PGIS formed the basis of its choice as the preferred method to gather information about stakeholder perceptions regarding four key sites of cultural infrastructure in Valletta. The data gathered was analysed by the author to understand its impact on stakeholder representations and potential means of how to encourage proactivity in participatory planning. To this end, a tri partite PGIS initiative was undertaken in Malta under the aegis of the Valletta 2018 Foundation and the University of Malta; with its spatial extent defined by the (Figures 1 to 5):

- Valletta Design Cluster at il-Biċċerija (translated as the Old Civil Abattoir);
- Strait Street Art, Culture & Entertainment Hub;

- National Museum of Art (known as MUŻA, an acronym for MUŻew nazzjonali tal-Arti); and the
- Valletta Indoor Market (known locally as Is-Suq tal-Belt).

Figure 1: Location of the four Cultural Infrastructure sites

Figure 2: The building that is to house the Valletta Design Cluster at il Biċċerija

Figure 3: The newly redeveloped Valletta Indoor Market

Figure 4: The former Auberge d' Italie, now housing MUŻA

Figure 5: Views of the context for the Strait Street Art, Culture & Entertainment Hub

The four sites of cultural infrastructure were developed in line with the objectives to be attained in the run up to the Valletta 2018 European Capital of Culture 2018. Their development followed very different trajectories and provided insights into the relationship between policymaking, market-led forces and stakeholder engagement. Issues of inner-city re-zoning to allow for increased investment were governed indistinctly by commercial demand and the consequent policy response. Stakeholder engagement too has been questioned, especially since the overtly participatory mandate of the Valletta 2018 Foundation was more in evidence in the development of some of the projects than in others.

It was in this socio-economic environment that the PGIS was implemented, with the aim of better understanding stakeholder aspirations on the yet undeveloped sites and opinions on those which were already developed. The ability of PGIS to gather both quantitative and qualitative information was the primary attractor for its use, since it was essential that stakeholder perceptions are directly associated with spatial geo-referenced locations. Another advantage of the use of PGIS was the ability to develop a tri-partite initiative which consisted of a stakeholder workshop, an online campaign and a mapping walkabout. All three projects were undertaken using Mapping for Change, a platform developed by University College London and for which a license was obtained for use by students and academics at the University of Malta.

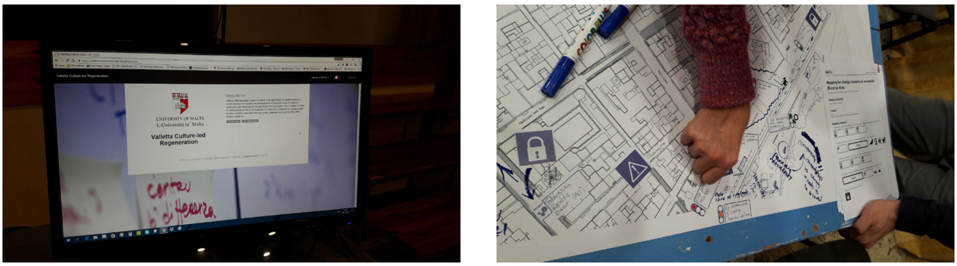
First Typology - Stakeholder Workshop

The first in the trio of PGIS initiatives was a workshop held in December 2016 with residents from Valletta who had previously participated in a series of stakeholder engagement projects organised by the Valletta 2018 Foundation. The workshop piloted the use of the Mapping for Change platform in Malta, for which this author designed, programmed and trialed a specific 'community map' in line with the objectives of the research project being undertaken.

The event attracted a small group with a strong interest in their locality and the changes they were witnessing. To this end, all participants were eager to learn how to use the online platform being piloted and all contributed to populating the map with contributions being inspired also by the simultaneous discussion taking place. The digital mapping session was complemented by a paper mapping session focusing on a different theme related to the built environment and this too prompted an inclusive debate. Overall, 35% of the contributions made during the workshop were directly mapped onto the online platform by the participants (Table 1); a relatively high rate considering that the participants had no prior experience of the platform and made use of it entirely voluntarily.

It was observed, however, that the digital mapping session created a degree of individuality since each participant was using a personal digital device and therefore one felt that the 'approval' of the group was not required prior to contributing to the map. This was not felt during the paper mapping session, where despite each participant being able to write on the map, more discussion took place. It is noteworthy that although participants could comment upon each contribution using the inbuilt functionality of the online platform, none took this opportunity; despite doing so through spoken communication.

Figure 6: Using digital and paper maps during the PGIS stakeholder workshop



Second Typology - Online Campaign

The stakeholder workshop was followed by a three-month online campaign between September and November 2017, during which the online platform was promoted on social media. Users were invited to build upon the contributions of the workshop by commenting upon them or by adding their own contributions. Though each promotion post was viewed multiple times and reactions made to it, no contributions to the digital map were forthcoming during the period of the campaign. Online participants did contribute to the map, but only after the campaign and these amounted to only 3% of the overall number of contributions (Table 1).

Third Typology - Mapping Walkabout

The third variant of the PGIS initiatives was the mapping walkabout, which enabled participants to contribute perceptions of the built environment following direct observation of the spaces they were experiencing in real time. The mapping walkabout took place during a conference organised by the Valletta 2018 Foundation in November 2017, entitled 'Liveable Cities – Liveable Spaces' a theme which reflected the objective of project for which the Mapping for Change platform was designed. Many conference attendees participated in the mapping walkabout, which was composed of a diverse group of participants in terms of nationality, occupation and age.

Figure 7: The three gifs created to promote the PGIS online campaign

Clearly, they were all interested in the theme of the project since they had voluntarily attended the conference of which it formed a part; a factor which probably contributed to the high participation rate experienced: 82% of all contributions from the tri partite PGIS initiative (Table 1).

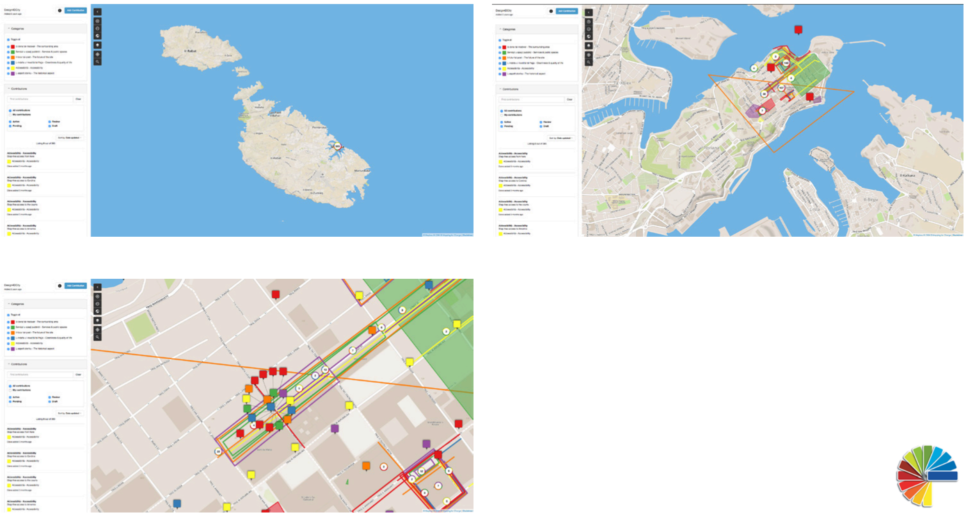
Prior to the mapping session, the participants were randomly assigned one of the four sites of cultural infrastructure and were guided by a coordinator familiar with the online platform, one of these coordinators being a Mapping for Change director. To gather as many contributions as possible, each participant was given a data sheet with the log-in details of the online platform and a map on which they could physically map their contributions. It was observed that only 12% of the contributions made during the walkabout were digitally mapped directly by the participants (Table 1), many not making the effort to familiarise themselves with the online platform and opting for the more familiar pen and paper approach. The approach taken was not related to digital literacy or related factors such as age; rather it seems to have been a reaction to the lack of familiarity in the participatory use of digital maps and the availability of another means with which to contribute in what was nonetheless an effective participatory mapping method.

Table 1: Table showing key data percentages

	Stakeholder workshop	Online campaign	Mapping walkabout
Percentage of participants	8%	6%	86%
Percentage of contributions	15%	3%	82%
Percentage use of digital platform	35%	100%	12%

Figure 8: Participants at the PGIS walkabout using the Mapping for Change online platform and paper mapping technique

Figure 9: Screen captures of the Mapping for Change platform showing the contributions at varying scales



Analysing Potentialities of PGIS In Malta

PGIS has not been used widely in Malta to date; and notably has not been used in any statutory representation processes required by the spatial planning system on the Islands. The initiatives carried out under the aegis of the Valletta 2018 Foundation elucidated the ways in which such participatory mapping methods can be used to achieve more widespread participation, more proactive responses from stakeholders and ultimately a more legitimate means of representation. Consequently, the processes of developing the PGIS initiative also provided a more nuanced understanding of stakeholder groups in Malta and brought to the fore the challenges faced by integrating such participatory systems in statutory representation processes.

Observing the efforts at stakeholder engagement made by the Valletta 2018 Foundation prior to the implementation of the PGIS, it is important to state that the method works best in tandem with other ongoing inclusionary initiatives and the gradual build-up of social and technical capital amongst a community group. Since the inception of the PGIS, such prior initiatives proved invaluable since the mapping platform was developed with themes extracted from a series of UnConferences which had been organised to gather insights of the community on their changing socio-spatial environments. It is believed that integrating the PGIS into an existing system of stakeholder engagement increased its feasibility and improves the chances of achieving legacy once particular projects are completed (Katz and Gonzalez, 2016).

Crucially, the PGIS must be designed to allow for participation by a varied group of stakeholders composed of members of different communities and who use the spaces for diverse uses. Massey (2005) notes that social geographies are in a constant state of flux and it was indeed the case that stakeholders and communities changed over the course of the project, as did the use of the spaces being analysed. The transformations witnessed during the development of the cultural infrastructure projects were not only physical, but also profoundly social. Gentrification, whether beneficial or otherwise, contributed to a constantly changing cohort of stakeholders, a factor which affected basic elements of the design of the PGIS, such as the requirement for the platform to be available in both Maltese and English.

It was noted that although the personal use of digital technologies is seemingly ubiquitous, digital inequalities persist (DiMaggio, et al., 2004; Mariën and Prodnik, 2014; Park, 2017) and were noticeable during the implementation of a tri-partite PGIS initiative. Park (2017) outlines four causes for such inequalities, namely access to basic infrastructure, the quality of connection, adoption of digital technologies and level of digital skills. It was observed during the PGIS initiative that though there is widespread internet provision in Malta, there are areas which are not yet 4G enabled. Despite providing a series of Wi-Fi hotspots through purpose-bought SIM cards inserted into the coordinator's mobile phones, these failed to operate successfully in Valletta. This was a surprising disappointment since it has been said that Valletta is to become a Smart City, therefore "a living environment enriched by ubiquitous technology" (Staffans and Horelli, 2014).

Also of note was that all participants of the PGIS initiative had personal digital technologies and a basic level of digital skills, though these varied considerably. Despite this variance, when carrying out participatory mapping in a small group such as during the workshop, participants were likely to give one another a helping hand in learning how to use the Mapping for Change platform. This was less in evidence during the walkabout, during which participants were grouped randomly by the organisers and which resulted in many opting to use the paper maps provided rather than to learn how to use the online platform.

Yet another variation observed between the three initiatives was in the contributions made by those who attended the workshop, mostly residents, and those who attend the walkabout, an international cohort of conference participants. The residents submitted very localised information based on personal experience whilst the conference participants made contributions based on passing observations. Nevertheless, the number of participants attracted by the walkabout was tenfold that attracted by the workshop, possibly because the fact that the organisation of the PGIS initiative as part of a conference on a related subject ensured that a cohort of interested participants would be readily available to take part.

The online campaign did not generate interest initially; with contributions being submitted only after the events had taken place and none during the time when the initiative was being promoted. One possible reason is the impersonal nature of this type of initiative, the other being the surplus of stimuli in the attention economy. These observations seem to indicate that the stumbling block to the participation in such initiatives is not the lack of opportunities to do so, but the lack of a proactive mentality to change to voice concerns and aspirations, especially when the subject at hand is not perceived to have an immediate and direct effect on one's personal sphere of interest.

The lack of proactive mentality may be fueled by cynicism towards decision-makers in the light of ingrained systems of patronage and clientelism (Boissevain, 2013); a cynicism that is mutual when one considers the inertia to integrate such participatory initiatives in statutory representation processes. These relationships between stakeholder and planner lead to a vicious circle of representations which are solely negative and reactionary, prompting a defensive stance by authorities that ultimately hinders the representations from resulting in actionable policy. Conversely, the PGIS initiatives generated a 60% positive and proactive contribution rate, tipping the scales towards the potential for positive dialogue between stakeholder and planner. Clearly, the tools available at the disposal of both the stakeholders to make their voices heard on the one hand, and the planners to garner more proactive representations on the other hand are available but are not being used.

Conclusion

The knowledge and experience gained from the organisation of the tri-partite PGIS initiative highlighted the challenges faced when dealing with complex spatial planning situations. Reducing these challenges to a balance sheet of costs and benefits or to a simplistic favouring of the majority party often disregards more intangible socio-spatial factors (Clifford and Tewdwr-Jones, 2014). Faced with the ambiguous task of acting in the public interest, planners encounter ethical dilemmas due to the inherent subjectivity and uncertainty in deciding the fair allocation of resources (Wachs, 2016). In their role as advisors to decision-makers and politicians, planners are therefore called upon to use all means at their disposal to understand such intangible socio-spatial factors.

Participatory mapping not only allows the planner to unearth stakeholder values, but also facilitates the stakeholders themselves to understand one another and to form a more cohesive group in the face of external challenges (Pink, et al. 2015). It has been proven that the method is useful to understand the socio-spatial background to spatial planning situations in an ethnographic manner, where a bilateral exchange of information and critical analysis of data can prove useful in the quest towards defining the public interest. It is also clear that PGIS is particularly suited to stakeholder engagement in local situations where in-depth socio-spatial knowledge is required.

In conclusion, the localised method intrinsic to PGIS remains relevant in an era where 'Big Data' is being used to extrapolate trends and decision-making is being informed by information gathered external to stakeholder engagement. Should the inclusion of minority groups and the nuances of intimate dialogue be considered a priority in planning endeavour, then interaction on a personal scale is a skill to be fostered. Participatory mapping is a means of achieving such interaction and when juxtaposed with the functionalities provided by digital technologies, is a powerful tool in a planner's repertoire.

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CHAPTER 14

An investigation of surface water flooding and social vulnerability in Malta

Maria Refalo

Introduction

Weather and climate exhibit a strong influence on human society in their everyday lives (Kazmierczak & Cavan, 2011). Surface water flooding disasters occur due to an overlap of hazard and vulnerable communities (Van Western, 2013). The process of climate change is envisaged to increase both in frequency and severity thereby creating climatic hazards such as flooding (IPCC, 2014). In extreme precipitation events, surface water flooding can lead to flash floods (Kourgialas & Karatzas, 2016; Tripathi et al., 2014; Tehrany et al., 2013). These events are expected to increase in their intensity (Tripathi, et al., 2014). A leading cause associated with these risks is the high-density urban areas and the development of infrastructures (Kazmierczak & Cavan, 2011; Tehrany, et al., 2013). The Maltese meteorological conditions are typically not severe. Nevertheless, weather conditions can be hazardous, especially with respect to flash flooding. In case of severe flash floods, areas would become inaccessible due to large volumes of surface water. Such surface water flooding subsides once precipitation stops. Notwithstanding this, the aftermath of flooding is significant.

Global Climate Change

The warming of the climate system, that is, climate change, is reported to be unequivocal by the Intergovernmental Panel on Climate Change (IPCC, 2014; Martinez-Grana et al., 2016; Sperotto et al., 2016). Global climate change is causing increased global temperatures, ice reduction, a rise in the sea level, and temperature fluctuations (Gravitani et al. 2016). Flooding is one of the most dangerous and threatening natural hazards to the social, ecological and economic sectors (Kubal et al.,2009; Haq et al, 2012; Abuzied et al., 2016; Tehrany et al., 2015; Ramlal and Baban, 2008; Micelli et al., 2008).

Flood Risk

With respect to this study, flooding refers to surface water flooding, also known as flash floods, where, in extreme precipitation events, can cause flooding (Kourgialas & Karatzas, 2016; Tripathi et al., 2014; Tehrany et al., 2013). Over the coming years, flash flooding is expected to increase, which may lead to catastrophic events (Tripathi, et al., 2014). In conjunction with the natural processes occurring on a daily basis, the anthropogenic factor is also significant (Spitalar, et al., 2014). High density urban areas and the development of infrastructures can further intensify associated risks, especially when changes are not present over a long period of time (Kazmierczak& Cavan, 2011; Tehrany, et al., 2013).

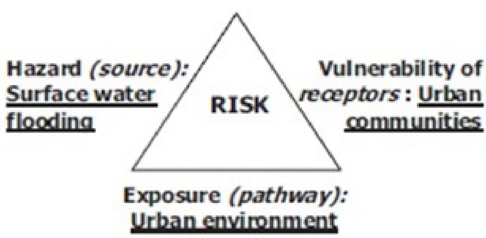
Most cities are located on flat ground with an accessible source of water where the land would have been fertile and suitable for crop production (Tingsanchali, 2012). This type of land use attracts infrastructure and industrial development, which in turn, increases transportation means (Tingsanchali, 2012). This implies that the denser the urban area, the higher the vulnerability to flooding. These areas are more susceptible to flooding due to a larger impermeable surface caused by buildings and transportation routes, which increase the number of hard surfaces such as concrete, at the expense of vegetation (Tripathi, et al., 2014). In such a scenario, a situation of flooding in an urban area may be caused by inadequate or insufficient drains, as well as low permeability (Sperotto, et al., 2016; Tingsanchali, 2012). In certain situations, unplanned development and urbanisation have brought about undesirable effects to the city (Tehrany, et al., 2015). Therefore, the practice of poor land use has backfired and forced a major change in hydrological processes (Suriya&Mudgal, 2012; Ramlal&Baban, 2008).

Flash floods cause multiple damages, which can be classified into two groups: direct and indirect damages (Tehrany, et al., 2013). The loss of life attributed to flash floods is a direct damage that can be prevented, whereas significant economic damage is classified as indirect damages (Ghozali, et al., 2016, European Commission, 2016; Few, et al., 2004; Qi &Altinakar, 2011; Kazmierczak& Cavan, 2011; El-Magd, et al., 2010; European Environment Agency, 2008; Tingsanchali, 2012). With respect to direct damages, the division between the "global North" and "global South" is evident (Fatti, Christina Elizabeth; Patel, Zarina, 2013). The balance of wealth is not evenly distributed, and a higher ratio of lost lives is recorded in the South rather than in the North. This disparity is the product of a lack of mitigation measures, preparedness and ultimately an actual flood mitigation management plan (Fatti& Patel, 2013). An example of indirect damages caused by flooding was exhibited in Malaysia, where 40 per cent of the country's damages are a result of flooding (Tehrany, et al., 2015). Another example of indirect damages refers to a declaration by the United States of a federal disasters bill of $4 Billion in property damages, spanning six years (Tripathi, et al., 2014). A single flash flood in Malta amassed a bill of €4.4 million in damages (Ministry for Transport and Infrastructure, 2013). Due to these financial consequences, climate change is deemed an economic problem. This situation calls for an adequate system of planning in terms of flood management. This is particularly important because adaptation to existing planning systems and urban infrastructure is less expensive than replacement costs (Gravitani, et al., 2016).

In a climatic event, hazard, both exposure and vulnerability indicate areas of high risk. However, risk is best described as the potential losses within the definite area of the hazard throughout the time of the event. This is a result of interaction between the hazards of an area (due to the natural background and anthropogenic influence) and the vulnerability conditions present in the community, depending on their preparedness to mitigate the impact (Van Western, 2013). Moreover, the magnitude of this risk will be reflected in the level of direct and indirect damages resulting from the event (Abuzied, et al., 2016). Access to complete data, with a view to mitigating the level of risk during an event, is a result of good governance together with clear visualisation of maps where Geographic Information Systems (GIS) is the latest technology used to produce and present such output.

In the event of a flood, there are three different spectra to look at to reduce the impact absorbed by the community, namely, hazard, exposure and vulnerability, which form the three main pillars of risk (Sperotto, et al., 2016) (see Figure 1). The three spectra also form the risk triangle (Kazmierczak& Cavan, 2011), where each spectrum is controlled to keep related risks to a minimum and ultimately reduce the risk level. In the event of a hazardous impact, the source is significantly linked to the extremity of the surface water flooding; therefore, the source is the hazard of the flooding event (Kazmierczak& Cavan, 2011). Whilst exposure is the pathway through which the hazardous event passes, leading to the vulnerable communities (Kazmierczak& Cavan, 2011). With respect to the last spectrum, vulnerability refers to the recipients of the hazardous impact which can be citizens, buildings and other economic enterprises (Kazmierczak& Cavan, 2011).

Figure 1: Three pillars of risk



Source: Kazmierczak& Cavan, 2011

Collectively, hazard, vulnerability and risk will serve to inform the Flood Risk Management plan with the where, when and how much it will cost in the event of a hazard, thereby allowing for better time management along with allocation of resources (Abuzied, et al., 2016; Tehrany, et al., 2013). As noted above, urban flooding is a result of natural and anthropogenic influences; nevertheless, the risk throughout a flooding event is a combination of hazard and vulnerability (Tingsanchali, 2012).

Hazard – surface water flooding

The term 'hazard' refers to a physical event that has the potential to create damage, either to people, property, community disruption, environmental decline, and economic loss. The hazard throughout the event can be recorded within a specified timeframe, throughout a defined area and the intensity with which it has impacted the locality (Van Western, 2013). With respect to surface water flooding, the highest risk is attributable to residents, as opposed to property, the community, the environmental decline and economic loss, since this event is more difficult to forecast (Kazmierczak & Cavan, 2011). Hazard assessment needs to be carried out on a national scale for a better understanding and knowledge of the country's needs, to have appropriate planning for the implementation of adaptation, which shows effective decision making (Van Western, 2013). For a clear perspective of the level that the hazard is at, a large collection of data needs to be sourced. In this respect, concerns emerge in terms of data quality, metadata and databases used by multiple persons (Van Western, 2013). Nevertheless, further improvement to the structure of hazard data is required as this information needs to be encompassed within a spatial data infrastructure.

Vulnerability

The vulnerability aspect within a flooding event is attributed to various aspects of our daily routine. This term is further subdivided into another four categories, namely, physical, social, economic, and environmental. It is the interaction of each category that can increase or decrease the susceptibility of a community to the hazard impact (Van Western, 2013). This can be observed in the different categories encompassed in this term, rendering it multi-dimensional. The basis of this concept dates to the 1970s and stems from the social sciences, in response to hazard perception during a risk event. In the field of social sciences, population datasets are the most important, as these are the highest element at risk during an event. Ideally, census data are used to analyse vulnerability since they represent the official record of the population at a specific time frame (Van Western, 2013). Most notably, the vulnerability relating to the social aspect refers to the potential impact of a hazardous event on communities within the same society. It is the degree of susceptibility to the hazardous event that creates the degree of vulnerability (Chang &

Huang, 2015). Furthermore, vulnerability has three components linked to it: exposure, sensitivity to the exposure, and the degree of system's adaptability (Chang & Huang, 2015).

Flood Risk Management

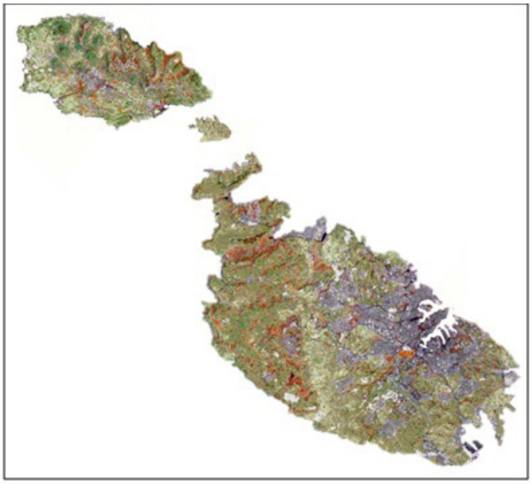
The protection required for a society to mitigate a hazardous event is twofold: hard and soft measures (Qi & Altinakar, 2011). Hard measures represent the physical infrastructure built for the protection of citizens, while soft measures refer to the preparedness of the community (Kubal, et al., 2009). Hard measures are more common than soft measures due to their tangibility factor, comprising mainly of ditches, rerouting of channels, and reservoirs. However, these infrastructures carry their own limitations, namely, clogged drains and overflows (Qi & Altinakar, 2011; Shimokawa, Shiori; Fukahori, Hidetoshi; Gao, Weijun, 2016). In terms of soft measures, flood warning and mass evacuation procedures are carried out (Qi & Altinakar, 2011). Directly tying in with this, is one's ability to adequately prepare for the event of a flood. This is an especially relevant for those with high vulnerability, including those with low levels of physical ability, such as children, persons with a disability, and the elderly (Kazmierczak & Cavan, 2011). Another soft approach includes the impart of knowledge on possible hazards to empower citizens with the skills required to enable them to carry out self-assistance in the event of a disaster (Shimokawa, et al., 2016; Fatti & Patel, 2013). Also of relevance to soft measures are protective behaviours, such as making sure that there is a working flashlight and radio in the house, having an emergency list readily available and preparing members of the family what to do in case of an event (Micelli, et al., 2008).

Furthermore, male members of a community are most of the time assumed to make sure that protective behaviours are established (Micelli, et al., 2008). A study into these behaviours would lead to an understanding of how a community has adapted to being on the receiving end of a flood (Micelli, et al., 2008). Over time the approach towards flood risk management have become more integrative in the society where an ecosystem-based approach is also being incorporated; which approach can safeguard the surrounding environment (Rouillard, et al., 2015; Piper, 2014). An example of a commendable flood management long-term plan is that developed in Japan, which includes four measures in respect of disasters, namely: management, promotion, post-disaster recovery, and the promotion of scientific and technological research, with the latter aimed at the continued enhancement of the plan (Shimokawa, et al., 2016).

Methodology – Study Area: Qormi-Marsa Catchment Area

As illustrated in Figure 2, the Light Detection and Ranging (LiDAR) image shows the grey area as built up, concentrated mostly towards the Central-South region of Malta, due to an intensification of urbanised areas (Politecnica Soc. Coop, 2010). The built-up area in Malta was 31.8% in 2016 (Planning Authority, 2016).

Figure 2: The Maltese Islands



Source: Formosa, 2013

Flooding in Malta is a common issue throughout winter, especially between September and January (Politecnica Soc. Coop, 2010). The meteorological conditions in Malta are typically not severe when compared to Northern Mediterranean countries. Nevertheless, weather conditions can be hazardous, especially in the case of flash floods. Areas hit with severe flash floods could become inaccessible due to large volumes of water, leading to road closures and obstructed pedestrian access to roads. The situation is controlled once the rain stops; however, considerable damage noted in the aftermath of floods should not be taken lightly.

Table 1 presents statistical data pertaining to rainfall throughout the last six years in Malta (MetOffice, 2017), collected from eight weather stations situated around the Islands of Malta. The weather stations located in Malta are found in Luqa, Msida, Bengħajsa, Valletta, Dingli, and Selmun, whilst those located in Gozo are found in Xewkijaand Xagħra. As shown in Table 1, significant variations in precipitation were experienced between 2011 and 2016.

When flash floods occur in the Islands of Malta, the hazard impact level can reach high levels due to large amounts of rainfall within a short span of time thus creating surface water flooding in floodplain areas (Politecnica Soc. Coop, 2010). Although no permanent rivers are found in Malta, which rivers may pose the risk of overflow in the case of a flood, watercourses dry up during the summer season and fill whenever a considerable amount of rainfall is recorded over a prolonged period (Politecnica Soc. Coop, 2010). In terms of flash floods, the hazard impact is mostly due to an increase in urbanised areas, brought about by land use change and weak drainage systems that do not withstand the rainfall capacity, or by the absence of drainage systems (Politecnica Soc. Coop, 2010). Moreover, impermeable surfaces caused by urbanisation are counterproductive, which results in a higher discharge rate of rainfall, implying that urbanised areas within a flood-prone area would have increased the level of risk (Figure 3) (Politecnica Soc. Coop, 2010).

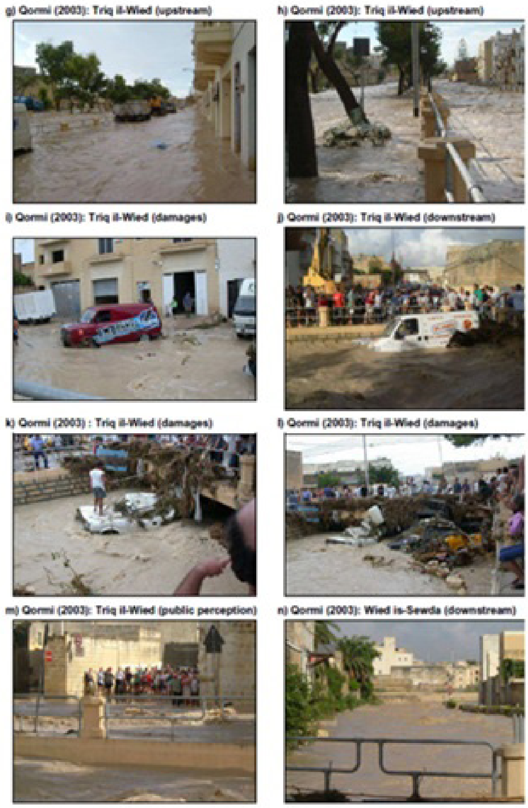
Table 2 shows the statistics that were found during the project that was carried out for the NFRP. It was identified that the total damages amount to millions and that this watershed area was the longest.

Table 1 - Rainfall Data for the last 6 years

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
2011	106	89.6	54.6	28.8	10.6	4.4	0.2	0	7.4	84.8	131.8	72.8	591mm
2012	67	132.6	58.4	21.8	0.01	0	0.01	0.01	85.2	46.8	61.6	45.8	519.3mm
2013	50.2	51.7	16.4	18.6	1.4	0.2	0	26.4	31.6	21.4	182	79.6	479.5mm
2014	58.4	58.6	44.6	13	5.6	2.2	0.2	0.2	0.2	82.4	88.6	150.3	504.3mm
2015	49.6	112.8	64	4.6	21.2	0.01	0.2	35.6	16.4	102.2	101.8	45.8	554.2mm
2016	28.2	2.6	23	3.2	12.2	32.8	0.4	12.2	26.4	24	99	60.8	324.8mm

Source: Met Office, 2017

Figure 3: Flooding in Birkirkara and Qormi



Source: Politecnica Soc. Coop, 2010

Table 2 - Information on Catchment Areas

Name of Catchment Area	*Watershed Area*	*Longest watercourse*	*Residents directly affected by the flooding*	*Residents Indirectly affected by the flooding*	*Total Run-off flow for the catchment area*	*Total Direct damages to buildings*	***Total Direct damages to infrastructure***	***Total loss for the economic sector***	***Total Social Loss***	***Total Damages***
Marsa	47.6km^2	11.9km	4,800	41,000	129.58m^3/s	€3,754,147	€0.99mi	€1.2mi	€500,000	€7mi

Source: Politecnica Soc. Coop,2010

Variables for Analysis and Results

Study area: Qormi- Marsa Catchment Area – Hazard

Digitisation of the hazard areas from the NFRP documentation was carried out by visual interpretation from the maps. As a spatial reference of the location, the orthophotos were used as the base layer in the digitisation. This study verified the flood hazard areas that the NFRP used for its project, whilst other data sets were overlaid on top.

The Digital Surface Model (DSM) derived from LiDAR will be visualised and overlaid on the orthophotos. Then using ArcGIS 10.3.1 software, the DSM will be overlaid on the water network model to ensure that the DSM topographical features correspond to the flow of the water direction, as explained by El-Magd et al. (2010), thereby establishing possible variations of flash flood hazards from the surrounding environment. This will aid to recognise the areas through which the flood plains are passing, hence providing a more accurate visual of the area. This analysis presents the expected scenario of the natural watercourse through which the water network passes, given the built-up situation as per 2012 (Kourgialas & Karatzas, 2016). It should be noted that some building construction has occurred since the water network model was created in 2012.

Furthermore, the NFRP used the water courses provided by the Planning Authority so that such model can outline the hazard areas within the catchments. This study has overlaid the water courses layer onto the water network model to establish whether the layer used in the NFRP had a similar water network model. The dataset corresponding to the water courses entailed a desk study. The data layer is a vector map which was created through a visual interpretation from the Orthophotos of 2012, using the contour map with an interval of 2.5 meters from the Planning Authority's base map. Hence, this study took these assumptions into consideration.

Following this analysis, the Energy and Water Agency (E&WA) vector data layer of flood hazard was overlaid with the risk areas from the E&WA available on the European Environment Information and Observation Network portal. This was compared to the NFRP data to assess consistency in flood hazard and risk areas, enabling the E&WA hazard and risk area layers to be overlaid on the digitised hazard areas. This was meant to confirm whether the hazard areas identified by NFRP were within the same delineation. Following this, the watercourses layer, the water network model, and the DSM were also overlaid. This verified how all such datasets were delineated creating a clear visual as to whether all the layers were consistent. The superimposition of the data layers could only be implemented once all the data layers acquired were in the correct geographic projection and that all the layers corresponded to the same coordinates, without any shift.

Study area: Qormi- Marsa Catchment Area - Vulnerability

The enumeration areas layer, as per the 2011 National Statistics Office (NSO) census, was imported into the land cover layer to create the thematic maps through ArcGIS, hence delineating the degree of flood risk exposure (Martinez-Grana et al., 2016). The NSO data included the following variables: age, gender, marital status, qualification, and labour status.

The vulnerability factor was analysed through the land cover of the catchment areas, which was created from orthophotos. This aided in the visualisation of the extent of the urban area that could be at risk, thereby presenting a combination of methods as outlined by Rouillard et al. (2015). Different methods have been applied to create maps of social vulnerability, including Hot Spot analysis (Zerger et al., 2002; Zerger, 2002) and Thematic Mapping (Kazmierczak& Cavan, 2011). Thematic Mapping provides a clearer representation of where the data are located. Hence, vulnerable locations can be analysed more accurately and the representation of this method proved to be more realistic.

The flood risk was evaluated through the three pillars of flood risk, as noted by Sperotto et al. (2016). In this sense the flood risk was investigated through a comparison of flood hazard, social vulnerability and exposure. As also analysed in Kazmierczak& Cavan (2011), the resultant comparison established the extent of the relationship between the social vulnerability indicators and the hazard presented through the surrounding environment, which environment leads to the susceptibility of risk from surface water flooding.

Study area: Qormi- Marsa Catchment Area – Flood Hazard Map

The Qormi-Marsa catchment area digitisation results the numerous areas of flood hazard. Figure 4 illustrates agricultural area although this was not digitised as in Figure 5. Apart from this divergence, the digitisation used the same areas as those presented in the NFRP map.

Figure 4: Flood prone area for Qormi-Marsa Catchment Area

Source: Politecnica Soc. Coop, February 2010

Figure 5: Flood Hazard Areas for the Qormi- Marsa Catchment Area

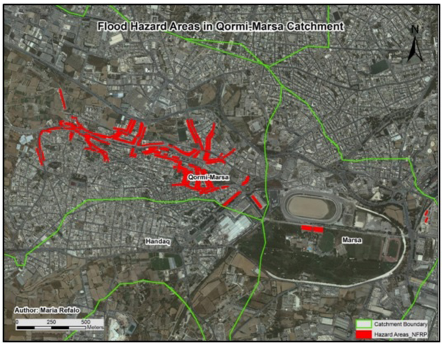
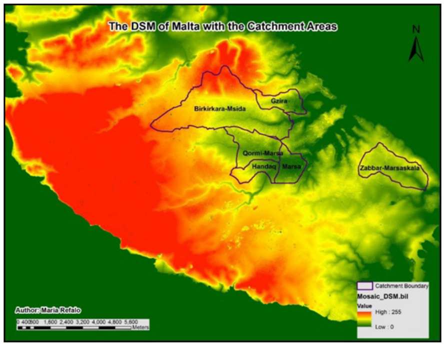


Figure 6:Malta DSM with Catchment Areas



Further to the digitisation exercise, this study checked if the DSM and water network model had the same topographical features. Similar topographical features ensure that the water flows in the same direction and follows the same building path. By establishing this, the study visualised the surface of Malta, thereby identifying the flood hazard that the public is exposed to (Figure 6). Moreover, the green colour in the DSM extends significantly towards the inland area. As a result, and with respect of the DSM, this study shows that the built-up areas are within the flood hazard areas.

As evident in Figure 7, the area in green extends through Marsa and Qormi. The DSM represents the flood plain area of the catchment, which also confirms the way the water network model developed, whereby the water is collected in the flood plain and moves towards the sea. The topography pertaining to the area shows that most of the water that flows through Marsa is naturally aggregated in the Marsa section.

Figure 7: Qormi-Marsa Catchment with DSM and Water Network Model

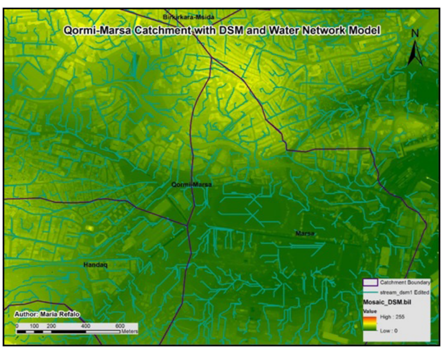
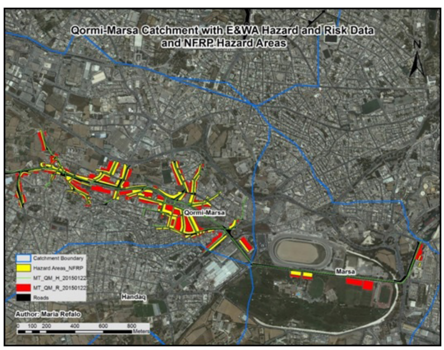


Figure 8: Qormi-Marsa Catchment with E&WA and NFRP Hazard Areas



Further to the above digitisation, the main study also shows the investigation of the overlaying of the named catchment area with layers of water courses data and the water network model. There was also the overlaying of layers from the Energy and Water Agency (E&WA) Hazard and Risk Areas, along with the NFRP Hazard areas as represented in Figure 8. Moreover, there was also the creation of the land cover for the catchment area which is illustrated in Figure 9. The vulnerability map below (Figure 10) shows Qormi and Marsa, which are one of the highest rankings for vulnerability. For this reason, these localities were selected for the public questionnaire which consisted of seventy residents in total.

Figure 9: Land Cover for Qormi-Marsa Catchment Area

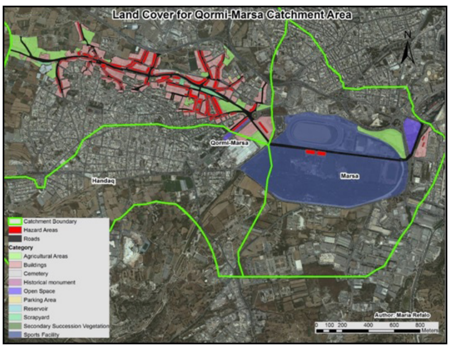
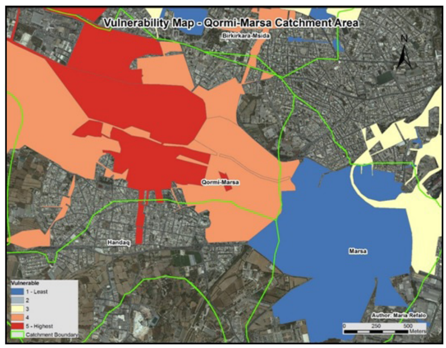


Figure 10: Vulnerability Map of the Qormi-Marsa Catchment Area



Although the results obtained from both the mayor of the local council and the public cannot be explained in too much depth, questions were raised in cases where the answers differed. Nonetheless, the feedback obtained from the interviews and questionnaires was optimistic. The situation that the residents were in before the NFRP was of high risk. Even though nowadays the situation still requires updates, improvements are clearly identifiable. The public perception confirmed that the mathematical calculations and plans prior to the implementation of the mitigation measures were well planned and served as a sound basis for the NFRP implementation.

Conclusion

The aim of this study was achieved through a comprehensive investigation into matters relating to surface water flooding. The different GIS models generated in this study provided a visualisation of the natural situation and what should be expected in cases of surface water flooding. These models identified the hazard areas, the vulnerability areas, as well as the risk areas. The public perception was investigated through interviews with the mayors of ten local councils and questionnaires with seven residents from within the risk areas. The Hazard and vulnerability maps were carried out through digitisation by the author and through the overlaying of other sourced layers. Overall, the hazardous areas were identified and through the census data, the vulnerability map was created in order to indicate the areas that needed more attention. Through the subsequent analysis, the flood risk map was created indicating Qormi as one of the localities most at risk.

Finally, it should be noted that the mayors and the public imparted varying perceptions on the results on the implementation of the NFRP. Even though both groups agreed that the implementation of the NFRP was a move in the right direction, the mayors of certain localities were more optimistic with regards to the effectiveness of the project. Nevertheless, on a general note, the results achieved through this national project addressed its initial objectives. This also confirms that this study generated an accurate analysis in identifying the areas at surface water flood risk.

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Pivot IV

Emergent Realities: Virtuality, Augmented Reality and Innovation Domain

Aerial Image: AI Generated Art
MidJourney App - SF

CHAPTER 15

(Re-) Capturing the Fungus Rock

Trevor Borg

Introduction

The Fungus Rock: Għerq Sinjur project represents a continuation of my ongoing research practice that delves deep into the fabric of place. Unlike the accessible places investigated through previous projects, that have always entailed a direct embodied sensorial experience, the fungus islet is strictly out of bounds (Figure 1). It has been like that for almost 300 years, well protected by law and now officially a designated nature reserve. Lanfranco (1960) attributes the legendary status of the so called 'fungus', which he describes as a 'relic of history' and 'awe-inspiring', mainly to the fact that it still survives in its original place. Also known as the General's Rock, this small rocky projection is a stone's throw away from the western coast of Gozo, however, its official ecological status and geological morphology make it practically unreachable.

The first decision that had to be made concerned the method(s) of capturing the islet's fabric in great detail, as close as being physically there. The decision fell squarely on the use of photogrammetry, defined by Colwell (1997) as a technology based on remote sensing and capturing of detailed information about objects and the environment through the recording and interpretation of digital images (cited in Ebert, 2015 pp. 50-51). A drone camera was used to enable the acquisition of highly detailed visual information of the islet's surface and sides, without the need to set foot on it. The forensic style, image capturing process, allowed for highly accurate topographic mapping of the islet's outermost composition, including the rock formation and the flora that thrives on its garigue-like surface and around its weathered sides. The captured imagery, initially in the form of aerial video footage, was then translated into a spatial model by means of photogrammetry software and point cloud mapping. The computer-generated model, based on real world data, was then simplified in terms of polygons, three-dimensionally printed and incorporated into a sculptural piece.

Figure 1: Fungus Rock, Gozo

Photo-Phenomenology

On my various data collection fieldtrips, I follow a contoured map embedded in the ground in search of directions (Borg, 2022). The specific research methodology I opt for, generally favours a phenomenological vein that entails being physically on site. In the context of this research project, the lack of a physically accessible site initially presented itself as a major obstacle, as I always start my investigation of place on foot, one step after another. Walking constitutes an integral part of my place-oriented research practice, however, this basic approach to place was not possible this time around. Such a hurdle, at the very beginning of the project, inevitably became one of the principal research questions: Is a direct investigation of place possible without ever being on site?

Mapping the terrain is what I do to collect different types of data that feed my artistic practice. My ongoing research considers phenomenology as a point of departure, echoing the words of Merleau-Ponty (2012 p. 330), that 'it is through my body that I go toward the world'; movement in place allows for direct embodied experience, tactility and discovery through sensorial possibilities. In the context of this project, the movement is not carried out by the body, but by a remotely controlled camera that goes round the object (under investigation) multiple times.

The object consists of a lump of limestone, standing firmly like a prominent barge moored close to the shore. It fits neatly Foucault's (1967) criteria for a heterotopia, however, as I shall explain, it might also share parallels with a utopia. Foucault (1967) tells us that the heterotopia might constitute a sacred or forbidden place, it has a specific function, it is capable of connecting multiple places (real and imaginary) and is often connected to slices of time. The little island under investigation encapsulates all of these aspects and, notwithstanding its very restricted footprint, like a heavily loaded palimpsest it packs layers upon layers of fabric waiting to be unpacked. Furthermore, Foucault (1967) argues that heterotopias 'always presuppose a system of opening and closing that both isolates them and makes them penetrable'; unlike public places they are not freely accessible 'their role is to create a space that is other, another real space'.

So what makes the Fungus Rock both a utopia and a heterotopia? I have already mentioned that the islet may only be accessed via drone, following the necessary permits from the authorities entrusted with its safeguarding. Foucault (1967) maintains that between the utopia and the heterotopia 'there might be a sort of mixed, joint experience' which could take the form of a mirror. The mirror, or for the sake of this study I shall refer to it as the 'mirror-image', has always played an important part in the realm of lens-based media. The drone footage and photographs utilize a highly specialized form of image capturing, whereby the image is captured on a sophisticated sensor that mirrors what is in front of the lens. The technological approach used to capture the Fungus Rock resonates with Foucault's mirror that acts as a portal connecting the heterotopia with the utopia.

'The mirror is, after all, a utopia since it is a placeless place. In the mirror, I see myself there where I am not, in an unreal, virtual space that opens up behind the surface; I am over there, there where I am not, a sort of shadow that gives my own visibility to myself, that enables me to see myself there where I am absent: such is the utopia of the mirror.' (Foucault, 1967)

There exists an ambiguous yet evident correlation between the mirror-image described by Foucault and my strategy to setting foot on the little island, virtually rather than physically. The deserted rock emerges in the form of a utopia, as opposed to the rest of the Maltese islands it remains completely untainted by contemporary development. Moreover, its heterotopic properties allow us to connect the present with the past, and to compare contemporary Malta with how we imagine it had been in times gone by. The sea separates and at the same time connects the main island and its little sister, and although the gap in between is quite narrow, they embody very distinct temporalities. In Massey's (2005 p.67) words, the smaller island harbours its specificities which are also in part the result of the connections and disconnections (and the combination of both) it has with the rest of the Maltese islands.

In Marg Augé's (2008) terminology the Fungus Rock might also be described as a 'non-place', given that it has always been a transitory place (or space); a place that could only be accessed in order to gain access to something else. The islet lacks human presence and except for the smoothening of part of its sidewalls, it is completely missing any form of human intervention (Refer to Notes 1). The Fungus Rock has a history and is encircled by myths in contrast with the typical 'non-place', however 'it does not contain any organic society' (Augé, 2008 p.90). It can only been accessed temporarily for very specific reasons and it has been segregated for ages. We might want to call it a quasi or atypical non-place since it does not tick all the boxes depicted by Marc Augé. One thing is sure, the size of the islet does not limit what it might become; on the contrary, the lack of physical space available on its restricted surface, opens up many opportunities for it to become an 'other place', in both real and imaginary terms.

Jutting out of the sea like an imposing mythical creature the tilted rock contributes in no small way to the dramatic surroundings in Dwejra Bay (Figure 2). The islet, situated only a few metres away from where the impressive Azure Window once stood, might also have been part of a cave that had been eaten away by the waves over thousands of years (Lanfranco, 2017) (Refer to Notes 2). In ancient times the roof of this 'hypothetical cave' could have quite easily been connected to the shore, probably later eroding into a fragile arch before totally breaking off from the mainland. Now, where the feet cannot trespass the drone will. Data meticulously captured by the drone while flying along a predetermined path constitutes what Mitchell (2002) defines as 'textual systems'. The acquired data of the islet's landscape was then interpreted by a computer application and translated into a spatial model that almost allows us to view all the cracks and crevices.

It is virtually impossible to collect such data through any other means other than by physically landing on the islet, to be able to observe and directly experience the 'vastly-diminutive' landscape up there. As Bachelard (1994 p. 215) asserts, restricted space accumulates size – 'it is vast in its way'. This 'vastness' can be attested by the richness of the visual data captured in the span of a few hours through the lens of the drone camera as it followed a pre-established virtual grid. Initially, the data consisted of two-dimensional full-colour images, laid out on a flat plane that lacks any spatial or geometrical structure. Merleau-Ponty (2012, p.318) argues that we might learn more about the object from colour rather than its geometrical properties as it is through colour and light that the nuances of the landscape and what we perceive as contours may emerge. Through photogrammetry software the contours of the rock are identified and traced out to establish its unity; a process that allows for a virtual being-there as 'our picture of the world can only be composed in part with being' (Merleau-Ponty, 2012 p. 287). The drone camera mediates the gap between the 'here' and 'there'; it makes dasein, as defined by Heidegger virtually possible. The next step in the process entailed extracting still images from the footage captured by the drone, to start giving it a three-dimensional form and transforming it into a tangible object.

Figure 2: Fungus Rock, aerial view

An Islet for an Islet

Hundreds of photographs were used to generate a detailed point cloud spatial model of the Fungus Rock consisting of huge amounts of data across the X, Y, Z axis (Figure 3). It is necessary to combine photogrammetry with point cloud as the latter translates two-dimensional images into points plotted in space required to establish correct spatial dimensions, contours and other physical attributes as per original object. A point cloud system allows us to see the object in three-dimensions, rotating and flipping it to explore all its topographical attributes. The resulting point cloud model was then converted into a polygon mesh which had to be simplified, in terms of polygons, in preparation for three-dimensional printing (Figure 4).

The model was three-dimensionally printed using Fused Deposition Modelling (FDM) that works by extruding and heating the thermoplastic and depositing it gradually in layers. While the model represents a highly accurate scale rendition of the fungus islet, it also makes for an 'other place' independent of the place of origin. Merleau-Ponty (2004 p.71) argues that a painting of a landscape, or in this case a sculpture, 'does not imitate the world but is a world of its own'. This claim takes us back to Foucault's heterotopia as the 'new' islet becomes an 'other place' (in between); yet it still connects us with the 'original' islet. We can encounter the Fungus Rock through the FDM model which allows for a total viewing, from all sides and angles, of the rocky protrusion out at sea. At the same time, it offers a different experience because it is not the 'original' islet; it can never replicate the so called 'original' but it may offer a different yet similar kind of exploration and overall encounter. The three-dimensional model might not share many characteristics with the Fungus Rock, as hardness, weight and colour, but as Heidegger (2008 p. 124) argues, object matter 'still remains what it is'. Furthermore, Heidegger points out that '(r)ising-up-within-itself the work opens up a world and keeps it abidingly in force' (original italics). Therefore, it can be argued that the FDM model is not a 'true' replica of the Fungus Rock but a relatively different islet, separate and disconnected from the place of origin. At the same time, the fabricated model still keeps us grounded in the place of origin and through it we may encounter aspects pertaining to the islet in the sea. Casey (2002) argues that a representation of place does not offer a transparent view onto its own subject matter; place cannot be replicated but transmuted or 're-implaced'.

Figure 3: Photographs generated from drone footage

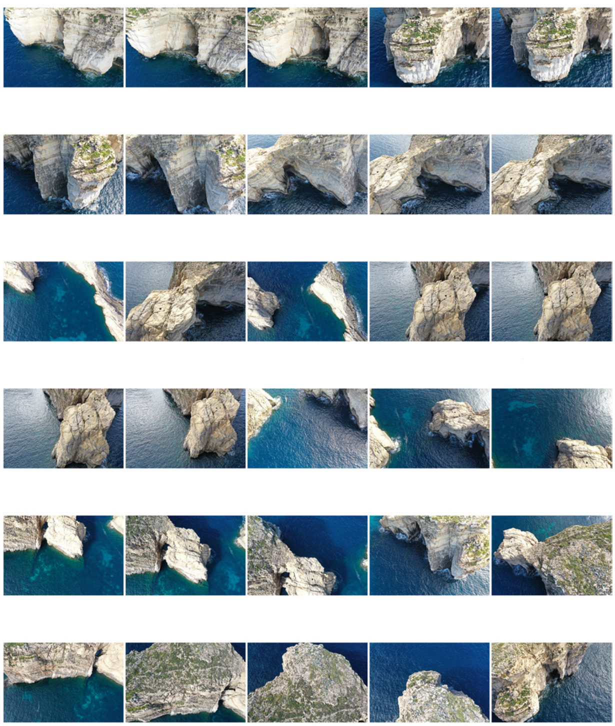
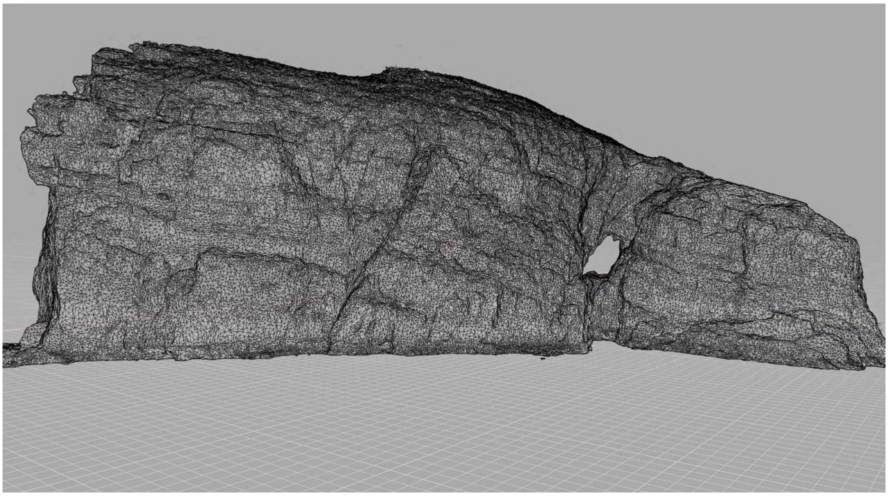


Figure 4: Fungus Rock - 3D mesh following point cloud model generated from photographs



The principal aim of this practice-based project is not to accurately replicate the Fungus Rock but to create a scale rendition that can be incorporated into a work of art with the intention of eliciting multiple questions. The point cloud model captures the topographical attributes of the islet and reterritorializes them into space and time. Moreover, the spatial model acquires further heterotopic characteristics since it is linked to a slice of time spanning the duration of the flight path covered by the drone. Baudrillard (1994 p. 11) tells us that 'everywhere we live in a universe that is similar to the original – things are doubled by their own scenario', hence the question, can we ever go back to the original place? Morton (2010 p. 55) maintains that the idea of 'authentic place' is a Western myth, a deception.

The title of the work, 'Fungus Rock: Għerq Sinjur' (2022), draws on the etymology of the Maltese words 'għerq sinjur', literally meaning 'rich root', referring to the fallacious properties that in the past were attributed to the pseudo-fungus (root) growing on the islet. The title of the piece plays on the homophonic characteristics of 'għerq' and 'qerq', where the latter loosely translates into 'deception'. The sound of these two words is aimed at provoking further layers of meaning that one may ascribe to the interpretation of the work. It is beyond the scope of the sculpture and this chapter to infer specific meanings or encourage particular conjectures as to what the sculpture might be trying to communicate. The aim is to provoke and incite questions by using the work and the stories surrounding the islet as a point of departure, or according to Bourriaud, 'to bring precarity to mind' (2016 p. 43).

Figure 5: Fungus Rock - Għerq Sinjur (2022)

Trevor Borg, mixed media sculpture

The FDM islet is enclosed inside a clear acrylic box supported by a white wooden base reminiscent of museum showcases (Figure 5). The choice of colours was based on achieving maximum contrast and to prevent the model from reflecting the controlled light directed towards it. The acrylic box sits on four 16mm steel rebars, that violently penetrate the base of the showcase to engulf the fragile islet inside. The rebars were treated to encourage rust and corrosion which immediately began to accumulate at the base of the showcase staining the pristine whiteness more and more with each passing day, as the sculpture continues to accumulate time. In large part, the chosen materials resonate with the work's thematic and the context in which the work is located. The viewers are invited to appropriate the materials entwined in the sculpture and reconstitute them into a work of their own, refashioning, interpreting and composing new meanings from the elements given to them (Rancière, 2011 p. 13). The work is not meant to illustrate facts; it is meant to problematise the factual and to imagine what that might become.

Morton (2010) implies that art has the ability to speak, it can make us question reality, it deals with shame, abjection, loss, reality and un-reality among other things. Fungus Rock: Q/erq Sinjur was exhibited at Teatru Astra in Rabat, Gozo in 2022, as part of a national conference and exhibition focusing on the island's identity. The space in the theatre's upper gallery became an extension of the work as visitors could walk around the sculpture to view the islet from all sides and angles. Programmable lighting was used to illuminate the work in a controlled manner, designed to direct the gaze of the viewers towards the sculpture and the space around it. The interplay of shadows on the walls generated an uncanny spatiality, adding more depth around the freestanding piece by introducing further 'ecosemiotics' (Kull cited in Barry & Welstead, 2017 p.4). Art in collaboration with other fields can be a catalyst in speaking the unspeakable, in revealing the concealed and in showing us how to look at things differently, more critically. One of the functions of art is to make us realise how our modes of thinking are contaminated by an anthropocentric assumption that 'only in relation to human beings that anything else acquires value' (Clark, 2019 p. 14). Fungus Rock: Q/erq Sinjur is an attempt at problematising deeply ingrained anthropomorphic thinking by taking us to a place where we are 'not supposed' to be and imagining what this place might become if we are ever allowed to be there.

This project is an attestion of a fruitful collaboration between art and science and the important contribution one field makes to the other and vice versa. Photogrammetry and point cloud systems open up endless creative possibilities in the realm of digital arts which could be incorporated into a wide array of art practices from sculpture, three-dimensional animation and game design to video art, industrial design and virtual/augmented/mixed reality and much more. Photogrammetry can be a powerful tool for artists but 'to get answers from aerial photographs, questions must be asked of them', and there is a wide range of questions to be asked ranging from the scientific to the artistic and beyond (Ebert, 2007 p. 50). One of the principal outcomes of this project is precisely that of asking questions and to encourage the viewers to ask questions about the work and what it might mean. Land mapping, in the context of place-oriented practice, has a lot to gain from an artistic and scientific entwining wherein photogrammetry definitely emerges as a key prospect. Systematic aerial photography, combined with creative methodologies pertaining to place-oriented practice, allow for artistic research opportunities and novel approaches to image making to continue to unfold.

Notes

1. The Knights of the Order of St John had smoothened part of the islet's sidewalls to make it less accessible from the sea. The islet could only be reached from an outcrop atop the shore via a hanging basket.
2. The Azure Window, a 28-metre tall natural arch in Dwejra Bay in Gozo, succumbed to a storm in March 2017.

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CHAPTER 16

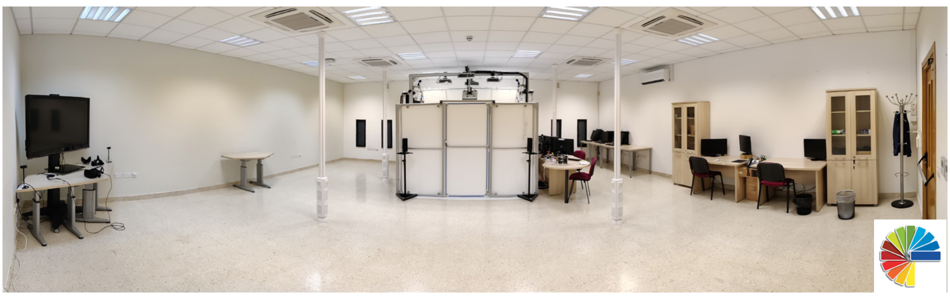
An Immersion Lab Presenter's Perspective

Fabrizio Cali

Introduction

The Faculty of Media and Knowledge Sciences hosts the MaKS Immersion Laboratory, (Figure 1), a space that houses various XR technology and related experiences (https://www.um.edu.mt/maks/). The MaKS Immersion Lab was set-up during the latter half of 2019 in a dedicated 9.5m x 9.5m room within the faculty. The initial inertia and planning stalled shortly thereafter due to the COVID situation, which hampered the progress of various facilities in early 2020, resulting in limited use of the equipment in the early years.

Figure 1: The MaKS Immersion Lab at the University of Malta



Source: Calì (2021)

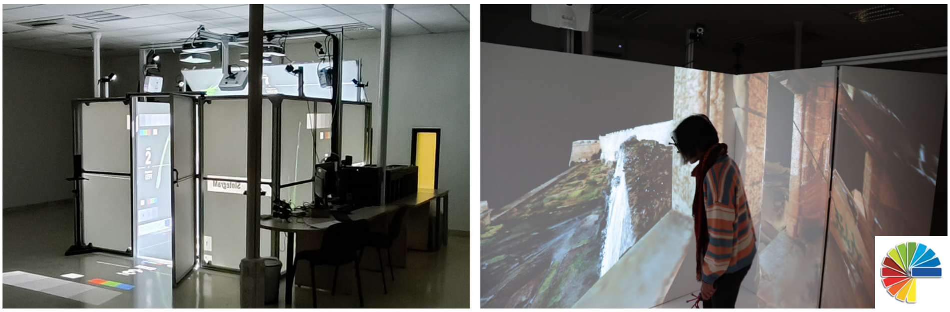
The Equipment

The SIntegraM Cave

The centrepiece is a six-sided C.A.V.E (Computer Automated Virtual Environment) (Note: Occasionally also expanded as the recursive acronym of "Cave Automated Virtual Environment") comprised of seven screens, each with its own dedicated short-throw Optoma projector. The floor has two screens/projectors to minimize shadow obstructions. The roof consists of minimal flap, at circa 45 degrees to complement the frontal screen. Each projector is run by a dedicated computer running Windows 10 and housing a Quadro P4000 video card. These are networked together and kept in sync through Quadro Sync II.

Input comes in the form of head and hand tracking using six dedicated infrared cameras. Trackable reflectors are mounted on one set of stereo glasses and on a Sony PlayStation controller wand. The stereo glasses used to view the experience consist of three radio-synced active glasses (Figure 3). Besides a computer for each projector, there is an eight computer to process user input, deploy the projects and run other core applications.

Figure 2: The SIntegraM C.A.V.E



Source: Calì (2021)

Figure 3: The equipment used for the C.A.V.E

Source: Calì (2021)

The project system as of 2022 is based on UniCAVE Plugin version 2.0 (Tredinnick et al., 2019), using Unity 2018.34f1 and adapted to our particular set-up. This is motion tracked by OptiTrack Motive 2.1.1.

Oculus Rift 1

The lab is equipped with the first-generation Oculus Rift with external sensors. Various Windows 10 PCs were used to run the Rifts. The Unity game engine is again the preferred development platform. Projects are occasionally run directly from Unity for faster iteration.

Note: Oculus Rift specifications: https://vr-compare.com/headset/oculusrift

Magic Leap 1 Creator Edition)

The lab (Figure 4) is also equipped with three Magic Leap One Creator Edition. Unity is again the current development platform of choice. Note: Magic Leap 1 specifications: https://vr-compare.com/headset/magicleap1

Figure 4: Cittadella project, Magic Leap Hardware, Otogarden project

Source: Calì (2021) - Otogarden Project: *https://otogarden.com/*

Miscellaneous Equipment

Besides the above, various other personal devices have been used by staff, students and guests including Oculus Quest 1, Oculus Go, and various Android devices through various Google cardboard devices.

The Lab Patrons

The lab has hosted a wide variety of guests since its inception. While some visits had a specific goal, most appointments were focused on introductory experiential visits to introduce the various technologies and discuss their possible application. Most visitors to the laboratory had no prior experience with VR or AR. Of those who did, Oculus Quest appeared to be the device mentioned most frequently for VR. Several of our guests were familiar with Pokémon Go which was frequently used as a point of introduction to AR and the Magic Leap. This is to be expected. Pokemon Go became the most popular smartphone game in history in 2016 (Zsila et al., 2018) and Oculus headsets have a significant share of the VR market (Kolmar, 2022).

In most of these situations the job of the laboratory presenter was to act as a lobbyist or advocate for the technology and its potential for the several fields in which it could be useful. A key point is to be as brand agnostic as possible by mentioning other brands including those not represented in the lab. Mention of early technological prototypes that could impact the technology is also important, to give an idea of where the sector could be headed. Hand tracking, lighter HMDS or contact lens screens like the MojoVision Lens are some of the frequently mentioned examples. Bulkiness is often cited by guests as one of the off-putting aspects of VR. Headset ergonomics are in fact frequently cited in studies as one of the negative aspects influencing uptake (Ciccone et al., 2021). Highlighting the potential advancement of the technology helps make the bulky HMDs currently available less of a liability and merely a steppingstone to what will be. This encourages the tech-averse to be a little less hesitant.

Methodology

The following is a non-scientific observation and analysis of visitors to the lab by the author who was responsible, or present for most of the activity in the lab. The lab visitors and patrons have been categorised as follows, in no particular order: European Commission and Government Entities, Industry Professionals, Academic Researchers, Legal Entities, School Children, University Students and Random Guests.

1. European Commission and Government Entities

Quite a few of the recurring visits come from government officials and other policy makers. These served a variety of purposes, from observing the practical application and the output of the funds they supervise, to a better understanding of what the technology entailed and how it could be used. It goes without saying that budgets are always limited, resulting in fierce competition between industries and sectors to direct funds to them. In such a situation one has to lobby for the relevant technology sector and demonstrate how the technology and relevant research as a product/service could directly benefit society at large and also how the creative industries that are developers for the technology would also grow as a result. This packages the technology and its output in such a way that it has positive impacts from both a sociological and economic point of view, two important pillars for policymakers.

2. Industry Professionals

Industry people, like VR game and app developers, have also visited the lab. This group often does not need much of an introduction to the technology and is already convinced of its potential. The value here results from the exchange of experience on different technology applications and critical feedback from a technological point of view. It is also beneficial for the university academics present to understand the needs of industry which could influence decisions related to future research or educational course programs.

3. *Academic Researchers*

Academic Researchers are regular visitors to the lab and generally come in three groups:

- The primary group are fellow researchers in similar sectors. These are like guests from industry. They are already familiar with the technology and its potential, which leads to an exchange of experiences, constructive criticism and discussions about joint research projects.

- The next category of researchers are academics looking to evaluate how the technology could expand and benefit their research area. These discussions are often rewarding as they open-up new opportunities for the laboratory to broaden its use cases and applications.
- The group consists of guest Lecturers who offered Immersion related projects in the lab. One of the major activities in 2022 were workshops conducted as part of the ErasmusXR program in which our faculty was participating (Note: ErasmusXR project website: https://erasmusxr.eu) (Figure 5). The workshops performed as part of the program gave our students exposure to a wider range of research projects from similar programs from other institutions or departments.

Figure 5: Students participating in various ErasmusXR workshops

Source: Calì (2022)

4. Legal Entities

One of the more exciting applications of this technology is in the legal field. Forensics makes use of several means of archiving onsite data such as photography and detailed floor plans. One of the major difficulties with such data is that it requires varying degrees of interpretation and experience on the part of the viewer to fully appreciate the inferred spatial dynamics represented by the media at hand. Understanding these spatial dynamics from a scaled 2D plan differs significantly from experiencing a physical 3D dimensional space at actual scale (Ye et al., 2022). While certain professionals may have considerable expertise in interpreting such data, the legal system also relies on non-professional individuals, such as jury members. Photogrammetry and other means of archiving a 3D space solve these problems by allowing third parties to experience the spatial dynamics of a place as they were at the time of the crime, long after the actual scene might have been altered, rendered inaccessible or possibly even no longer exist.

This is not without its difficulties. 3D data capture, unlike photography, is not currently instantaneous. This introduces a set of variables such as moving lights and shadows, or objects which could result in inaccurate artifacts in the collected data such as reflected spaces. Colour fidelity, for example, is still an actively explored area (Gaiani et al., 2017). Furthermore, the captured data then needs to be processed by various software algorithms to output interpreted data in the form of point clouds or 3D surface meshes and textures. This very process of data processing further introduces inaccuracies and errors possibly distorting the scene. The quality of the scan itself and conditions under which it was captured, the complexity of the scene captured, the type of surfaces and texture in the scene, and the level of detail required, can all impact the final output. While this may appear to be a problem, particularly in a setting requiring high fidelity such as forensics, one needs to focus on the purpose of the data. If the aim is to capture larger spatial dynamics, then minor inaccuracies or distorted textures might be negligible. The data will not replace other means of documentation but supplement it. Finally, the technology used to capture and interpret the data is constantly improving such as the technique developed at Olympia (Sapirstein, 2016). Data fidelity in this sector will improve as it has in photography and other areas.

The educational aspect is also relevant for the legal applications of VR. Criminology students for instance could revisit, and potentially interact with crime scenes, years later in a virtual environment.

School visits

By far one of the more entertaining guests at the laboratory have been children and teenagers. The aim here is to inspire probable future researchers, industry practitioners and policy makers. It was therefore key to mention possible study routes and careers that could lead to, benefit from, or make use of the technology and to also present a future world they could very well inhabit and which their children in turn would take from granted as current young generations take mobile phones and internet access as a given (Figure 6). Most children appeared already familiar with the technology in the form of games like the Pokémon Go on their phones or Beat Saber on an Oculus Quest (Beat Saber. (2022). In Wikipedia. https://en.wikipedia.org/wiki/Beat_Saber). This made illustrating the various other applications of the technology besides entertainment important.

Figure 6: Visitors from local schools

Source: Sciberras obo SEM (SEM European services in Malta: https://sem.gov.mt/) (2022)

University students

The university students to make the most use of the laboratory where undergrad students of the Department of Digital Arts, as part of their Immersive Experience Design study-unit (Study-Unit DGA2018 https://www.um.edu.mt/courses/studyunit/DGA2018). Most students did not own personal VR devices and had minimal experiences with XR. Giving them a wide range of experiences was therefore an important step to inspire and broaden their expectations. Besides research and serious applications, the students were also given an opportunity to try out various commercial games that allowed a variety of differing experiences (Figure 7). The following were the primary games chosen:

- *Oculus First Contact* was used as it provides a great introduction to object interaction and manipulation (Oculus First Contact https://www.oculus.com/experiences/rift/1217155751659625/).
- *Superhot VR* was selected for its use of time-based mechanics. (Supershot VR https://www.oculus.com/experiences/quest/1921533091289407/)
- Thrill of The Fight VR served as an example of Exergaming, a fitness-oriented sport simulation game. (Thrill of the Fight: https://www.oculus.com/experiences/quest/3008315795852749/)
- *Dr. Grordbort's Invaders* on the Magic Leap was used to demonstrate an Augmented Reality game to show virtual assets interacting with the real environment (Dr. Grordbort's Invaders, n.d.). https://world.magicleap.com/en-us/details/com.magicleap.invaders

Figure 7: Students exploring VR experiences

Source: Calì (2022)

7. Random guests

The final category of guests are generally unplanned or casual visits by university staff or external visitors who are visiting the faculty and are curious about VR. These guests are always welcome. The XR technology gets considerable media exposure especially through major brands like Meta but the market penetration is still relatively low. This makes the Immersion Laboratory an important ambassador for a technology, which will very possibly become as ubiquitous as smart phones, and which can positively disruptive impact in several sectors like medical and education ('Virtual Reality (VR) Statistics 2022 - Market Size, Usage & Trends', n.d.). This highlights the importance of higher education in its role of promoting innovation beyond its campus, influencing economic growth and development (Brito, 2018)

Project Set-Up

The lab equipment: Pros and Cons in the context of our projects.

Our projects primarily consisted of outputs from the SIntegraM project, an EU funded project to develop Spatial Data Integration for the Maltese Islands (SIntegraM project: https://sintegram.gov.mt/sintegram/). As a result, the primary inputs to the lab are Photogrammetry generated models of various localities around Malta and Gozo. These models are then deployed to the various devices in the laboratory through dedicated projects for each device. The hardware identified in the lab was mainly acquired through the SIntegraM project

File Formats

The models received are in FBX or OBJ format and consist of several million vertices and with 4k or 8K png textures. The actual number varies on the size of the site in question and the level of detail of the outputted mesh. Generally, FBX models are preferred as they import into Unity considerably quicker. Unembedded textures are also preferred to minimise import time in case the mesh or some of the textures needs to be reimported.

Material and Shading

On import the materials are frequently set to Unlit shaders, since the textures already have light and shadow data within them from the data capture. In the case of situations where interactive lighting needs to be added, then an effort is made to try and reduce the captured shadows (Figure 8). While there are dedicated delighting software these seem to currently be geared towards individually scanned objects and do not appear to be suitable for complex scenes composed of several spaces and objects. My personal approach is to use a combination of filters in Adobe Photoshop as a brute force solution. This has proven reasonably effective in a situation where the scene involved relatively homogeneous appearance and texture.

Figure 8: (a) original texture. (b) with colour corrected and shadow reduced

Source: Calì (2022)

Collision meshes

Collision meshes are used as colliders for interactivity. These meshes are significantly simpler than the visual meshes and may not necessarily match the visual surface exactly, depending on the scope of the project in question. The remeshing was done primarily with the open-source Blender 3D, which offers various tools to simplify or retopologise meshes at the expense of UV map data.

When a mesh needs to be reduced in complexity while preserving UV mapping it is either:

- regenerated from the source data;
- Meshlab is used as it allows for mesh simplification while preserving UVs. This works better with models that have larger UV islands (Meshlab: https://www.meshlab.net/); and

- In the case of heavily fragmented, small UV islands, the preferred option is to unwrap the reduced mesh with new UVs and bake the original textures from the original mesh to the new mesh. This allows for finer control and optimisation.

Comparing Technologies

The general order of presentation in the laboratory is almost always:

- The SIntegraM CAVE
- VR Headsets (Oculus Rift 1)
- AR Headsets (Magic Leap 1)

Occasionally, Google Cardboard or Augmented Reality on smartphone or tablets is also demoed. These are rarely prioritised since access to these technologies is simple even outside a lab setting. A quick example would be Google AR animals viewable on most recent smartphones (Figure 9) It is therefore preferable lean in on the technologies the visitors are far less likely to come across such as the CAVE and Magic Leaps.

Figure 9: Demoing Google AR animals

Source: Calì (2022)

The SIntegraM CAVE

The CAVE is described first because it is the most overt piece of equipment in the room. It is therefore the de facto attention-getter most guests will be eyeing curiously on entering the lab. It is also the more relatable experience because it can be introduced by way of 3D cinema films. Most of the guests have already experienced a 3D film at the cinema at least once. Asking the guests about their experience with 3D films also allows the presenter to gauge their familiarity with similar technology and set a reference point for their expectations. It also has the added advantage of eliciting unprovoked feedback on their 3D cinema experiences and if these are generally enjoyed or not, or if their past experiences have triggered motion sickness, headaches or discomfort.

The key differences between a 3D film experience and the CAVE:

- The CAVE surrounds you with screens creating a more immersive experience.
- The stereo glasses are active rather than passive, as usually found in cinemas. Different syncing technologies are available. The labs glasses are kept in sync with the stereo projections by means of a radio frequency.
- The CAVE has motion tracking to keep track of head and hand position through IR cameras.
- The point of view of the projection can therefore change based on the tracked head position. This is a crucial difference compared to a standard 3D cinema where the projection is consistent regardless of relative viewer position.
- The Tracked controller allows for scene navigation and/or interactivity depending on the project setup.
- Multiple people may view the experience simultaneously (three in our setup) but the second and third viewer are not tracked and therefore have no influence on POV and will see the POV of the primary tracked viewer.

The presentation is concluded by highlighting the pros and cons of the CAVE and how our set-up and use-cases could differ from other CAVE set-ups, as well as comparisons to other technologies in the lab.

Pros:

- Ease of access and use. The cave is particularly suitable for technophobes or individuals who are not too keen to wear bulky and heavy head-mounted displays.
- It easily allows shared in-situ experience; allowing individuals to see each other and the same projection. This facilitates discussion without anything lost in translation via digital avatars.
- The controller is simple. The PlayStation navigation wand looks quite straightforward compared to the bulkier game controllers.
- The depth illusion can be quite effective. Our guests have expressed fear when flying high above ground or ducked when a low wall appeared to be heading for their heads.

Cons:

- Contrast is one of the major limitations. Seven projectors in a confined white room result in considerable bounced light, resulting in decreased contrast. Darker scenes therefore work better than brighter scenes. Some solutions to alleviate the problem were as follows (Figure 10):
  - Leaving a black background for the models rather than introducing a nicer blue sky whenever possible.

    - Putting a 'shadow caster' parented to the tracked head. This meant that behind the primary (tracked) viewer was always obscured and did not contribute unnecessarily to bounced light.
    - Ensuring that the controller pointer was a darker subdued colour rather than something bright.
- Motion Sickness appears to be experienced most frequently in the CAVE. A solution if to put the most vulnerable in charge of the controller and tracked glasses. That allows them to be in control of speed of movement and proximity to models , thereby reducing the Vection effect which is one of the factors that can trigger motion sickness (Carvalho et al., 2017).
- The structure of the CAVE can also be problematic. The aluminium frame is prone to slight movement over time, resulting in misaligned screen projections that need to be regularly recalibrated.
- Development for anything requiring physics requires a network development approach. Each screen projection runs independently of the other so extra development is required to make sure any procedural behaviours are kept in sync across each screen.

Figure 10: Lack of contrast on display

Source: Calì (2021)

The Oculus Rift

Since Google Cardboard or Oculus Quests are the devices most visitors are likely to already have experienced, the Rift is generally the least novel of the lab technologies and used as a buffer between the CAVE and the Magic Leaps. This does not mean the experiences do not have their strengths.

Pros

- Experiences are generally more immersive since the headset shuts you off completely from your surroundings.
- The system allows for darkness and higher contrast so experiences that require darkness will be effective.
- Colours are vibrant
- Development iteration is faster since you can visualise and test the project directly on the device directly from the development environment.
- Can handle huge data since the primary limiting factor is the attached PC platform rather than the headset.

Cons

- Portability is an issue since the Rift requires a computer.
- The Rift 1 is tedious to set-up due to the external sensors.
- Requires recalibration if the sensors are moved.
- The attached cable is a hazard.
- Can be disorienting to some because the real environment is completely obscured.
- Can be dangerous to the user or 3rd parties if they move into the safe zone.
- Likewise, can be dangerous to the user or any nearby objects that are moved into the safe zone or if the safe zone is incorrectly marked.

The Magic Leap

By far the favoured device in the lab and therefore presented last.

Pros

- Highly portable.
- Allows visibility of real environment.
- Meshes the surrounding environment. This allows the system to:
- to occlude the virtual visuals based the real environment.
- To generate visuals on most real surfaces
- To allow the virtual to interact with real surfaces.

Cons

- The display screen is smaller than the viewing area. This is one of the most frustrating aspects of the Magic Leap as it distracts from virtual experiences that need to envelop the entire frame of view of the user.
- Does not work in dark environments and loses calibration.
- Additive process over regular the environment. Therefore, the brighter section of virtual vs real will be visible.

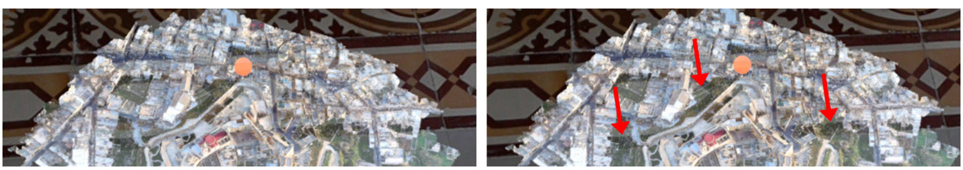
- This makes experiences that require dark areas impossible.
- The graphics work best when bright and saturated giving everything a hologram appearance clearly distinguishable from the real environment.

Regardless of current limitations, the Magic Leap presents an exciting view of what is possible in the near future and the how seamless and ubiquitous Augmented reality is likely to become in the near future (Figures 11 and 12). The Otogarden project (Oliva, 2021) depicts a game that was ported to Magic Leap.

Figure 11: (a) Otogarden adapted to Magic Leap.
(b)&(c) Kappa game character escapes game and runs around lab

Source: Calì (2021)

Figure 12: Floor tile pattern visible through darker areas.



Source: Calì (2021)

Conclusion

One would consider the initial couple of years of the MaKS Immersion Laboratory to have been a success. This, despite all the usual teething issues related to new project set-ups, troubleshooting and familiarisation, all of which were also severely compounded by obstacles related to the COVID situation in recent years. All visitors and users appeared to react positively to the various experiences. This was evident even when these experiences triggered some minor discomfort or motion sickness. There was more frustration from the need to cut the experience short in these individuals, rather than a negative reaction to the experience or technology itself. This is a promising reaction, especially considering that the technology is developing and improving at a rapid rate, with some of these improvements specifically geared towards making the experiences more pleasant, seamless, and natural.

Another very positive observation by the author, is the considerable uptick in students expressing interest in pursuing further research, or careers, related to various XR areas. This was particularly pronounced in the first cohort of BFA in Digital Arts students who were the first group to experience the MaKS Immersion Lab as part of their studies in 2021. One cannot help but look forward to seeing this how this technology can positively impact society going forward.

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CHAPTER 17

Using human decisions to program autonomous vehicles

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Introduction

Research on Self-driving (or autonomous) cars is gaining track and with the investment of various multinational companies. The motivation behind these vehicles is to reduce traffic, pollution and road accidents. However, an important ethical issue surrounds this new technology; if the car comes across a scenario in which harm to itself or another party is unavoidable. Should it save its passengers and make the decision to injure others, or should it sacrifice the passengers and avoid injuring other drivers or pedestrians? Given that there is no option to avoid any injury in such situations, who is responsible for the injuries/deaths that occur? Would people be inclined to buy such a car? These questions all stem from how the underlying algorithm of the self-driving car works. Since machines make calculations faster than humans, they lack a sense of instinct, and will have to be programmed to make such decisions consciously based on logic (Bonnefon et al., 2015).

This study builds on the findings of (Bonnefon et al., 2015) by introducing new cases including differently aged people and other cars as well as providing the option to sacrifice yourself instead of others. An online game that was made available to the public was designed and built. The users playing the game had decide who/what to hit in various scenarios presented during gameplay. This was preferred over a survey as it will lead to more reliable results by giving the players the opportunity to see the people being hit, and thus being able to easily picture themselves in the situation and react as they would in real life, rather than simply reading text and having time to answer in a way they deem correct. The results obtained from this experiment will be presented in the last section of this paper.

Background

The resultant decision in such situations is not always a clear and logical one. The philosophical idea revolving around this problem has been explored in various work. This section aims to outline the philosophical background upon which the decisions will be made.

Trolley Dilemma

The trolley dilemma was first introduced by Foot (1967), and was later built upon by various philosophers by introducing new variants (Costa, 1986) (Nucci, 2012). The trolley problem is intended to test the ethical prowess of people, with its aim being to determine if the persons judgement is utilitarian or not. This dilemma is often posed through the following thought experiment. You are the driver of a railway tram, which can only be steered straight or to the left tracks. There are 5 men working, and only 1 man working on the left track. Anyone on the track is bound to be killed and you cannot stop the tram in time. Whom would you kill? Would you take action to sacrifice the one for the many? (Thomson, 1976).

Consider another similar scenario. The tram is heading straight towards 5 people and cannot stop. A man is on the foot bridge with another rather large man. The man notices the tram heading towards the people and realises that if he pushes the other large man into the trams path, the people will be saved and only the heavy man will die (Thomson, 1976). According to utilitarianism, in both cases sacrificing one man's life to save 5 others is equally right. Foot (1967) suggests that we should not think this way. She believed that picking the left track and killing one man is different from pushing a man in front of the track. She believes the latter is morally unjust, insisting that it is one thing to steer towards someone foreseeing that you will kill him, and another to aim at his death as part of your plan.

Ethical Paradigms

Utilitarianism considers actions as morally right if they produce the best possible outcome and therefore maximise the overall good (Driver, 2014). If a person is going to kill a group of people, then it is acceptable to kill the attacker since doing so will save many more lives. This approach is based on impartiality, that is, everyone's happiness is given equal importance. The means to reach the same consequences do not matter. Thus, using this approach, aiming a gun to his head for a quick and painless death or torturing him till he dies will both be considered acceptable and equally right since the outcome is the same; he dies and the group is saved. Using this school of thought, utilitarians playing our game should always choose to kill fewer people, regardless of their age or gender. However, when posed with deciding between two people, other characteristics must be taken into consideration. For example, killing an old man rather than a kid would be considered morally right using such an approach. This is because a child may bring about more good in his life in contrast to the time that an old man has to live.

Virtue Ethics emphasizes the role of morality and character in one's choices (Athanassoulis, 2004). If asked to help someone, a virtue ethicist would deem it only moral to give aid. On the other hand, a utilitarian will first assess the situation to determine if helping that person would result in the greater good. Such ethicists live according to the saying "Do unto others as you would be done by" (Hursthouse and Pettigrove, 2016) and aim to act as a virtuous person would in any situation.

Deontology is an approach that emphasises duty and rules (Mastin, 2008). Rather than focusing on consequences or character, deontologists focus on the morality of the actions themselves. This means that an action is considered right or wrong independently from the situation. For example, if a doctor was just informed that his family was killed in a car accident by a drunk driver and was asked to perform surgery on the drunk driver, the doctor will be conflicted. On one hand, it is her duty to save the drunk driver, but on the other hand she does not wish to aid the person who killed her family.

Deontologists reason that an action is considered moral if it can be made into a maxim, such that it becomes a norm. Thus, they argue that it is the doctor's duty to help the drunk driver. A utilitarian would counter this by saying that by choosing to let the drunk driver die, less people will be killed in the future as he cannot drive under the influence of alcohol again if he does not survive. People who adopt this approach will choose self-sacrifice since it was their car which failed and thus it is their duty to ensure that no one gets hurt. Even in cases where citizens are not following the law (e.g.: crossing the road when the lights are red), deontologists will choose to kill themselves as the action of killing someone is always wrong no matter the given circumstance.

Social Dilemma

A social dilemma refers to situations where there is a conflict between personal and collective interest. Such a dilemma is applicable to many areas, including self-driving cars. In their paper (Bonnefon et al., 2015) concluded that most people would prefer to buy a car that will ensure the safety of its passengers at all costs. However, they would want other people to purchase a utilitarian car even if this means that its passengers might die. Thus, people tend to take the selfish approach for themselves, but do not wish others to do the same.

Literature Review

(Bonnefon et al., 2015) aim to study people's judgements in order to reach conclusions on the appropriateness of programming Autonomous Vehicles (AVs) to follow a utilitarian approach. They conducted numerous surveys, each aimed at collecting data on the moral compass of participants. In their first study, the participants were asked if driverless cars should sacrifice the driver to prevent the deaths of 10 pedestrians in circumstances where harm is inevitable. Their work showed that the majority (76%) agreed that it is morally acceptable for an autonomous vehicle to adopt such an approach.

In the second experiment, the same situation was presented but the number of pedestrians varied. The results showed that they did not agree on sacrificing the driver if only one pedestrian's life was at stake. This attitude changed when more pedestrians' lives were involved. Their opinions did not shift when they were asked to imagine that a family member or friend was in the car with them. In the next study, participants were asked to allocate points to different algorithms depending on the morality of the algorithm, how comfortable they were with having AVs programmed that way and how likely it is that they would buy such a vehicle. The algorithm which swerved into a single person to save 10 people was preferred, while the algorithm which swerved into a pedestrian to save another pedestrian received few points. The algorithm which killed its passenger to save 10 lives received a mixture of opinions. The results showed that people thought utilitarian cars are ideal for others to buy but would not invest in one themselves.

Self-driving cars guarantee that traffic accidents will decrease significantly, since most of these can be attributed to human error. An example of cars which have succeeded in performing very well in real environments are those made by Google, now called Waymo (Wymo, 2016), which travelled millions of miles around the United States. It is very difficult to avoid all accidents that can occur in the complexities of the real world, and some decisions need to be taken by the car itself, such as, the most ideal direction to crash into. Manufactures and regulators should aim to achieve 3 goals: firstly, that of being consistent, secondly keeping public outrage to a minimum, and finally encouraging buyers. When buying a car, one of the features that a buyer looks for is safety. However, if the cars system is utilitarian, people may be discouraged from buying because the idea makes them uneasy.

Therefore, manufacturers and regulators should study the results of surveys that employ this kind of experiment. Multiple surveys were conducted to study users' decisions in un- avoidable accidents. Participants were asked to input basic information such as age, sex and religion.

In the first study, around 400 participants were asked to take part in a survey. They were given a scenario where an autonomous car, which does not have time to stop, comes across pedestrians randomly crossing the street. They were asked if the car should swerve into a barrier, and therefore, kill its passenger or keep going straight and hit pedestrians (killing either 1 or 10 pedestrians). It was concluded that the most preferred action was to maximise the number of lives saved, even when it meant killing the passenger. They were also asked if they would consider that, in such scenarios, the driver must always ensure that the most lives are saved even if s/he must die should be enforced by law. Participants were more willing to consider legal enforcement of the sacrifice when the decision was made by a self-driving car, rather than by a human driver.

In study 2, the researchers wished to determine if people would consider buying a car which always aimed to save the most lives, even if the driver must die. Although people said that they would be supportive for others to buy such cars, they would not buy one for themselves. The results also showed that males were more likely to be interested in buying such a vehicle.

In the final study, participants were instructed to imagine themselves in the car, or to imagine an anonymous character. They were once again asked if the car should swerve or remain on its course as well as how they expected future driverless cars to be programmed. Three fourths of the participants believed that autonomous vehicles should self-sacrifice to save more lives. However, a smaller percentage believed that self-driving cars will be programmed that way by manufacturers.

Such studies show that people react to situations in different ways and thus there is no clear answer as to how these vehicles should be programmed. However, due to the increasing amount of traffic accidents, the importance surrounding autonomous vehicles is growing, with hopes that they will reduce the frequency of the accidents as well as the damage done. Thus, it is important to keep searching to find a solution to the reasoning these vehicles should adopt in cases of unavoidable harm.

One drawback from the previously mentioned papers is that participants were never made fully aware of the rush of emotions experienced during a situation such as the Trolley Dilemma. These emotions might interfere with the thought process and might cause people act differently than when presented with the same situation on paper. (Navarrete et al., 2012) studied this phenomenon by setting up a Virtual Reality (VR) environment where people were able to experience this dilemma through their own eyes without causing harm to anyone. In the scene depicted through the VR, participants were shown a boxcar track. The track on which the boxcar was driven had five workmen on it, while another track had only one man. The participants had to choose the fate of those men by selecting a rail for the boxcar to drive on.

The experiment was posed in one of two different ways for each participant. The action condition experiment tested to see whether participants would pull the lever to move the boxcar from the rail of five to the rail of one, i.e., taking the utilitarian approach. In the omission condition experiment, the roles were reversed. If the participants refused to take any action, the boxcar kept moving straight and killed one man. The results showed that the Utilitarian approach dominated whether this was done actively (by pulling the lever) or passively. In the experiments, 90.5% and 88.5% of the participants respectively chose to save more lives.

(Skulmowski et al., 2014) created a virtual reality experiment to investigate the decisions in the context of sacrificing a victim in a trolley dilemma scenario. Different characters were used in the scenario to rep- resent the different gender, ethnicity and orientation in space. (Li et al., 2016) tackle two main issues, the first of which being To which target will people allocate responsibility for an accident involving an autonomous car - to the producer, the owner, or the car itself? while the other being Do people expect autonomous vehicles to take utilitarian actions when facing moral dilemmas?. In both situations, the participants were given one from six scenarios to read and answer.

The first study was closely linked to the responsibility of actions. Participants were given scenarios where very similar situations were considered, for example having one case where the car was fully autonomous while in the other the car was driven by a human. Results from these statistics showed that participants held the human driver much more responsible when compared to the autonomous vehicle, even when the vehicle itself was at fault. In the case where the fault was of the pedestrian, both the autonomous car and the human- driven car scored low responsibilities. Participants felt that the government should be held responsible in the case of autonomous vehicles. This left participants with an uneasy feeling at the thought of being able to purchase such a vehicle.

The second study targeted whether or not such autonomous vehicles should always consider the utilitarian approach. Three car situations were considered; the autonomous car, the normal human-driven car, and a handover car where the hu- man driver takes control of the vehicles during the time of action. Similar to the first study, participants were given text descriptions which described the trolley problem. Results from this study showed that three thirds of the participants opted for the utilitarian approach. Evaluating results closer showed that 82.5% in the autonomous car would have opted for the utilitarian approach, 75% in the handover, and 67.5% in the human-driven car.

In conclusion to both studies above, the autonomous vehicles never seemed to be held responsible for their actions, but rather the manufactures who programmed such vehicles. Moreover, participants also opted for the utilitarian approach in order to save five lives and sacrifice the one. (Malle et al., 2015) study and compare the morality of the choices taken by human and robotic agents facing the same moral dilemma. They aim to compare the levels of blame, permissibility and wrongness, given by participants, of the actions taken.

Given tough choices, people tend to weigh in norms, emotions and consequences to determine the best possible action to take. However, they might also reach the decision unconsciously, based on intuition which cannot be fully justified. But how should robotic agents tackle such decisions? Typical studies aim to reveal the norms applicable to a situation by asking volunteers to indicate whether an action is acceptable, permissible or one they would have chosen. In their experiments, Malle. et al., (2015) extended this by showing the participants the same situation with a robot, rather than a human, performing the action. This was done in order to test whether the same norms would apply to robot agents.

Two experiments were carried out. In the first, participants were shown a scenario involving 4 miners working on a track in a coal mine, with a train heading straight towards them. They were asked to take the bystander approach by asking if it was permissible for the repair man (or robot) to redirect the train to another track and kill a single miner. Moreover, participants were asked to explain the reasoning behind their choice. The same scenario was presented to them again. This time, they were told which action the repair man (or robot) had chosen. They were asked to specify whether the agent should be blamed for taking such an action, as well as the reasoning behind their decision. The same scenarios were presented to the participants using the other agent instead. The results showed that both humans and robots were de- serving of more blame when they took action to direct the train and sacrifice one person. However, the actions of robotic agents were deserving of more blame more for not acting when compared to humans.

In the second experiment, the same scenario was provided to the participants. The action taken was specified, and the participants had to determine whether the action was morally wrong or not, as well as the reason behind their choice. They then were also asked to answer these questions for the same scenario using the other agent. In both cases the same action was chosen (ex: divert train). The results showed that less people considered the sacrifice taken by the robot to save 4 people as morally wrong when compared to the human that made the same choice. In contrast, the human agent was blamed less for inaction than the robotic agent. Thus, they considered the robot's intervention as more acceptable than the human's intervention. These results seem to indicate that robots are expected and possibly obliged to make utilitarian choices.

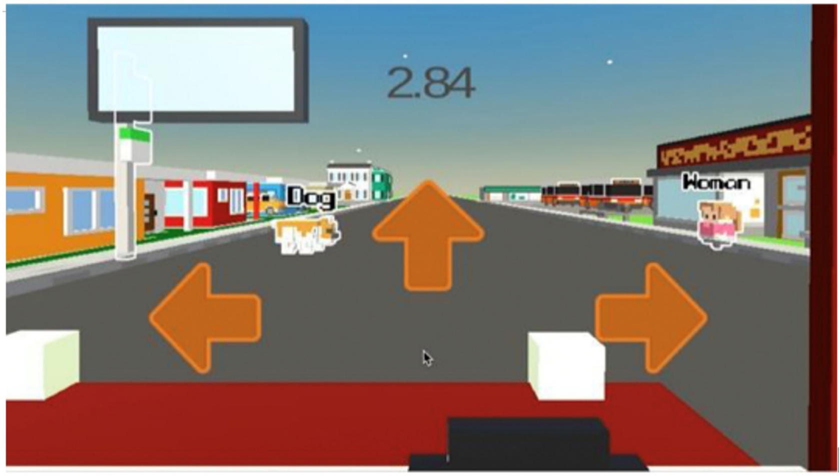
Methodology

The game that developed for this study was named 'Drivers Dilemma' and is a simulation of this experiment. The player is in a self-driving car which is unable to stop. Throughout the game, the player is presented with multiple scenarios. In each scenario, the car is unable to stop in time and thus the player must decide who should die. The player can choose to crash into a pedestrian who is crossing, a stationary car, a dog, or a group of people, each time different according to the scenario. We extend the dilemma by adding the option of self- sacrifice for each scenario. In some cases, the player must choose between killing one or a group of people. Other times, the player must simply choose between two different people. The player is encouraged to look at the type of person first. For example, killing a pregnant woman would result in the loss of two lives. Furthermore, in some cases, one option would be to crash into a car. Hitting a car (rather than a pedestrian) will lessen the chance of death of another person, since the other driver may still survive. Lastly, we also included dogs to see if people view animals as less worthy than human beings.

Design

The graphic style adopted for this game is pixel art. The decision was taken on the bases that no undue distraction is added to the simulation where participants are distracted by realistic graphics. This, something simple as pixel art is ideal for this experiment. This choice of graphics was also chosen due to their simple structures and little rendering which is ideal for a web-based game to not have lag that would compromise the user experience. Up-beat music and simple, colourful graphics were chosen in order to keep the game lighthearted despite the underlying dark situations it portrays. This will help people think more clearly and focus only on the choice ahead rather than the world around them. Players could exit the game at any time since their choices were sent on completion of each scenario. This ensured that the player did not get bored and select random answers for the scenarios. Thus, the collected results were more reliable and portrayed the true opinions of the participants.

Figure 1: A screenshot of the game showing the user's choice whilst a Dog (on the left) and a Woman (on the Right) are crossing the road



Scenes

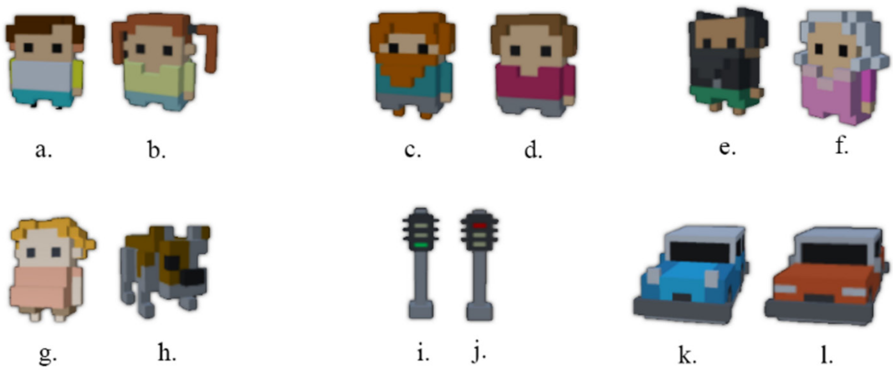
Scenes were carefully designed to ensure that focus is kept on the decision being made during gameplay. The following principles were followed to reach this objective:

- Characters and the environment were outlined to create contrast and therefore facilitating spotting of targets within the scenario:
- Labels were placed above the target to make sure the user does not waste precious time remembering the representation of the character or mistakenly choosing an incorrect character:
- Buttons, controls and timer were placed in fixed locations to ascertain focus;
- Music was added to the scene in a looping sequence so that the users would remain focused on the tasks with minimal acoustic distractions; and
- Part of the car was also shown to reinforce the driving experience.

Characters

In order to obtain the results for our study, various characters were used in the game. Each character has its own pre-set path. Upon loading the scene, the specific characters placed in the scene are chosen at random with the help of the Scene Controller script. The following list contains all the persons one may come across throughout the game as presented in Figure 2.

Figure 2: The characters presented in the game: (a-b) Little Boy and Girl, (c-d) Man and Woman, (e-f) Elderly Man and Woman, (g) Pregnant Woman, (h) Dog, (i-j) Traffic Lights, (k-l) Other Cars



Evaluation

In this section, the results obtained from the web simulation are aggregated for evaluation. The following set of points are critical for this evaluation.

Participants

In total, 511 participants played the game, putting in 4083 responses covered in scenarios that were played by the users. 64.19% of participants were males (328), playing in 2604 (63.77%) responses, while 33.86% were females (173), playing in 1428 (34.97%) responses. The rest (1.95%, 10 participants), identify themselves with other genders. 19 participants were under 18 years of age, 453 participants fall in the 18-34 age-group, 28 participants were between 35 and 54 years old, and 11 participants were over 55 years of age. Nationality of participants consisted of Canadians, Australians, Maltese and Americans.

Most Killed or Saved Characters

From the 849 scenarios that the dog appeared in, it was killed in 54% of said scenarios. This result contrasts a lot with the other characters in the game. The only exception is groups of old women, where dogs were killed 16% of the time and old women were killed in 38%. This result shows that participants believe that preserving human life is the most important choice.

Children and adults were killed only 15% and 18% of the time respectively, whereas old people were killed 35% of the time. Gender also plays a small part in the choices made, as males were killed in 24% of the scenarios presented, compared to females at 21%. The results show a tendency where the participants choose to save a life depending on their age. The younger the character, the bigger the chance that his/her life is saved.

Discrimination based on number of lives saved (Utilitarian Approach)

From the 933 scenarios in which participants were presented with a group of characters against another single character, only 159 (17%) chose to kill groups. The rest either chose to kill themselves as the car passenger (47%), or to kill another pedestrian (36%). Killing the least number of lives possible was of utmost importance to the participants, with 83% of responses indicating that it would be better if one person is killed, either car passenger or any other pedestrian, rather than a group of people. This result is comparable to the findings presented by the papers discussed in the scientific review. As seen previously in the study by (Navarrete et al., 2012), the most preferred action was to maximize the number of lives saved. In their study, most participants actively or passively (take no action) choose to sacrifice themselves rather than killing a greater number of pedestrians Similarly, numerous studies mentioned (Bonnefon et al., 2015).

Discrimination by Age

Participants preferred saving young children, In fact 18% of children were killed verses adults, and only 10% were killed against elderly people. Additionally, this trend of saving younger lives is also present when comparing adults to elderly where only 16% of participants chose to kill an adult in this scenario. It is empirically clear that participants tend to prioritise people by age. The younger the life the higher the possibility of saving.

Time Taken to Make Decisions

On average, it took the participants 1.36s to make a choice from the maximum of 3s given for each scenario. Only 10% of the users did not take any action within the 3s time window. Thus, taking into consideration only responses in which action was taken, the average time is remeasured to 1.18s. This means that only 16% of the responses chose in the last available second. An overwhelming majority (75%) of participants assessed the scenario presented and took action in less than 2 seconds.

The average time taken for a decision increases slightly becoming 1.41s when a group of people is presented in the scenario. These results therefore help in determining whether autonomous vehicles should ask the driver to take a decision when the scenarios presented by simulation occur in real-life.

Killing Self vs. Killing Others

44% of participants decided to kill themselves. One of the factors that could have played into this decision was the fact that the accidents were partly the driver's fault, since their own car brakes were failing in the scenarios presented by the game. When comparing between genders, most male participants, with 52%, chose to kill themselves, against the 47% of female participants and the 43% of participants who identify themselves as other genders. When evaluating which characters, it emerges that participants would save all human characters rather than save themselves. However, when presented with dogs, only 37% of participants decided to kill themselves. Furthermore, 56% of participants decided that it is better to hit a car (killing its passenger), rather than kill themselves. When presented with a group of characters, an overwhelming majority of 74% decided to save the group.

Conclusion

Overall, we can deduce that the experiment did satisfy our initial objectives. We wanted to extract heuristics which are implicit in most humans so that they can be used in autonomous vehicles. By doing so, the choices performed by these vehicles are not simply based on a pre-programmed algorithm which decides who is going to get killed based upon the bias of a pseudorandom number generator. Essentially, we are coding ethical decisions so that the choices performed by the autonomous vehicles have some ethical basis.

From the results, it is clear that saving human lives is of utmost importance to people. The life of a dog was seen as less valuable in most scenarios. Whenever possible a crash with another car, where the other driver has a chance of surviving, was more favourable rather than running over a pedestrian (where the chances would be slim). Although this was quite expected, it is still an important to note that autonomous vehicles should aim to prioritise human lives over anything else in cases of unavoidable injury. Our study suggest that self-driving vehicle should with a mechanism to calculate the probability that the other car driver or pedestrian survives the crash. This would ensure that it is truly the safety of the people involved which is being considered. It is also expected if other animals are used in the scenarios, they will be killed more often since dogs are seen as pets and are friendly to humans.

Continuing the point of saving human lives, the utilitarian approach was the most common methodology used among participants. The number of lives which were saved had a significant effect on the choice of the participants, with many opting to kill the few instead. It is valuable to note that there were a number of different variables which were analysed and saving the highest number of lives was one the most influential factor out of all of them, with only 17% choosing to kill a group of people. It should be noted that the groups in this simulation were represented by five people at once, and that the results might vary depending on the number of people within these groups.

The age of the people being saved was also a notable factor. The younger the person, the more likely that they were to be saved. This choice usually follows the reasoning that the young still have many years left in comparison to the older counterparts. Interestingly, pregnant women were the most saved character when groups weren't involved. This further confirms the previous points, since saving a pregnant woman can be viewed as saving two lives at once, with one of them being of a very young age.

Whether the other people in the scenarios were following the law or not was also taken into account, albeit briefly. However, the difference was slight and thus it might stem from the fact that some participants did not observe the scene well and thus did not realise such details. A further study could make the laws which people are following or disobeying more obvious to the participants, to get a better indication of how much it changes their perception.

An option which was explored in this study is the ability to sacrifice your own life in order to save others. Quite a large percentage of people chose that option when they were faced with the alternative of killing another person. This shows that not all people would want to ensure the safety of the driver at all costs and might want autonomous cars to also give priority to other lives as well. However, it must be noted that in these scenarios it was the driver's own car which was at fault, and therefore further studies could look into what happens if the accident is caused by someone else.

Thus, from the experiments conducted, we can easily summarise the results as follows:

- Human life takes precedence when compared to an animal life (dogs);
- If possible, hit another car; nearly 45% of participants decided to hit a car rather than killing themselves or other pedestrians. Probably because the result of the impact would be unclear since the car would absorb part of the hit and thus shield the passengers from it;
- Groups of people are more important; 82.9% of responses prefer killing a single person (car passenger or pedestrian) rather than groups of people;
- When there is no other choice, sacrifice oneself rather than killing other people; participants prefer to kill themselves rather than killing any other character (except dogs and other cars);

- Save younger people participants; prefer to kill elderly people rather than adults or children; and
- Save law abiding people; around 53% of participants saved law-abiding characters.

These results shed a lot of insight on how people think that autonomous cars should handle such scenarios. Further re- search could determine whether participants would want to buy or use autonomous vehicles, and the extent of autonomy that they would want such cars to have. Taking into consideration the presented scenarios, would self-driving car users want their car to take the final decision, or would they prefer if the car waits for the user's decision? What happens if the user does not make a decision in time?

Another possibility which can be explored in the future is an extension to the previous issue i.e., the fact that there can also be other passengers in the car with the driver. Depending on whether a family member or a stranger is involved, the rates of sacrificing themselves or the lives of people out- side the car is also expected to change. Also, the amount of immersion of the simulation can be improved with the use of Virtual Reality instead of on a screen, to make the participants experience the emotions typically evoked by such situations. During this study, participants were also asked to enter their Age, Gender and Nationality before starting the game. This provides an opportunity to use the data of this experiment through the model presented in (Seychell et al., 2012). This would then shed light whether there is a cultural influence behind the decisions being taken by drivers.

In conclusion, we believe that even though our experiment gives an interesting insight in the topic, we still have a lot of questions left unanswered. However, we believe that the path of ethical codification is the one we should adopt because after all, we want our safe-driving cars to act as ethical as possible taking into consideration the value of human life and the importance of preserving it.

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CHAPTER 18

Digitisation, Digitalisation, Digital Transformation: The Maltese Spatial Encounter

Saviour Formosa and Janice Formosa Pace

Introduction

The transformation of society is a slow generational process buffeted by a rapid change occurrence that is governed by a push-pull digital factor. The latter has spurned change that pushed the PREFE (Politics, Religion, Economy, Family and Education) societal foundations to embrace Technology. No longer do these domains operate in isolation, each with its own set of rules, dogmas and regulations, having become unobtrusive as technology infiltrated each domain through access to information in an interconnected global network. However, the resultant data-information-knowledge pivots facts emanating from the access to such huge volumes of material may not have rendered facts as a basis on which to build one's theories-assumptions=knowledge upon. This chapter's scope is to aid in the understanding of the need to create baseline datasets, information systems that are related directly to verifiable data cycles upon which researchers can build theories, policies and enable decision-makers to base their work on sound ground.

The process is based on a spatial rendition of the data creation process that is built around the digitisation-digitalisation-digital transformation tripod. As the Digital Transformation of the Real World entails the need to move from analogue to digital to virtual realities, the attempts to recreate that reality into a digital twin is enhanced through multi-domain, multi-disciplinary integration systems (Boggs, 2012). As detailed in the introductory chapter, the past two decades have been dedicated by researchers and policy makers to morph from a purely analogue reality to a part-digital and a quasi-full digital reality. In turn, this process pushes society to employing a bottom-up approach to the concept of digitisation and digitalisation. Through data, information and in turn knowledge, action can now be taken up by policymakers and decision-takers to ensure that all are ready for a new research and analytical operand: an operand that pivots on the Digital Transformation through strategic, operational and tactical activities as the fourth industrial revolution takes hold (Lachvajderova at al (2021); Vrana et al, (2021).

It is best to view such transitions through Jason Bloomberg's (2018) drive to understand the tripod as one move from a digital to a digitalized to a digital transformative domain:

- Digitisation is the process of converting analogue into digital format.
- Digitalisation focuses on the adaptation processes.
- Digital Transformation is the process of acquiring knowledge from the data into information for future action through creative means.

This chapter explores the processes employed to take cognizance of the digitalisation of the spatial domain, presenting the steps undertaken and posits cases upon which the processes were introduced in the Maltese Islands.

The Digital Realm

The digital realm has gone beyond the mere scanning of physical maps into images or pdf formats but is pushing towards the extraction of data, information and subsequently knowledge from features emanating from the vector and raster models that comprise spatial information (Câmara et al, 2001). The digitisation process, whilst still ongoing as legacy map-based documentation is voluminous, has been superseded during the past decade through digitalisation as driven by legislation and change imperatives such as the INSPIRE Directive (European Parliament, 2004) and international integration initiatives that built on successes achieved over the past years in various domains: These include the Environmental Sciences (physical, natural and social), Heritage and Archaeological Disciplines, Development and Spatial Planning, Forensics and Scene Recreation, as well as Transport and Utilities. The list is endless as new domains partake to locational data bridging the gaps between the domains and allowing for cross-thematic analysis. In turn, the resultant aim of this study aims towards research on immersions, sensors, gaming, art, metaverses, education, medicine, societal impacts, ICT, AI-human interactivities as each pushed words social wellbeing.

The challenges faced a decade ago was one where the Data Cycle was suffering from DRIPS (Data – Rich – Information - Poor Syndrome) as data was available in spreadsheets or flat tables and linkages between them were not possible. Data was expensive and creators needed to recoup costs. Cost effectiveness was further complicated by the need to create cost-recovery measures using copyright and access restrictions. Such was eased one the digitalisation aspect gained ground and entities started working on the digital transformation processes to ensure the maximum benefit from the new information constructs available. Cognition is spatial constructs is central to the transformation (Edwards, 1997; Klippel et al, 2012)

The spatial transformative cognitive processes adhered to cover the following:

- **Conceptualisation** of the spatial elements to transform through an attempt to define what is a direct reflection of the original concept of need, a difficult task indeed.
- **Entitation as the process by which one defines the entities about which one seeks to collect data**
- **Quantification** through an understanding of how rich is a rich dataset? Is the transformation required relative or absolute? Will proxy or surrogate data be used that represent the analogue data into a digital form?
- **Validity** that pertains to the peace of mind that data that was collected is a close representation of reality. The importance of ensuring acid-test for datasets of dubious origins cannot be stressed overly as the result is as reliable as the source.
- **Composition** in spatial domains is of paramount importance as it is the process by which multiple individual indicators are combined into a composite model, which serves as the turf ground for spatial information systems.

The Maltese experience in handling the transformation process was governed by a hands-on approach that delivered the 3D CloudIsle (www.cloudisle.org) spatial information used in many domains, the CrimeMalta 2D spatial output (www.crimemalta.com) and the SIntegraM geoportal and various others (Planning Authority, 2012) as developed on the initial project ERDF 156: Developing National Environmental Monitoring and Infrastructure Capability (PPCD, 2014).

Challenges to the transformative process

Challenges to the process revolve around the lacunae in the transformation process as the state has readily available technologies and little on the theoretical approach as well as the operational processing, the process will reduce the Digital Divide and empower students and experts alike to be prepared for innovation. The challenges ahead focus on the thematics that would be taken up by this initiative through theoretical focus and implementation of practical initiatives on the following:

- Real-World Digitisation and Digitalisation;
- Intra and Inter-Domains Interactivities: Terrestrial, Aerial, Bathymetric;
- Digital Design – Visualisation and Visualization;
- Data Cycle: capture, input, cleaning, storage, analysis, output, reporting;
- Technologies: Laser, photogrammetry, robotics, remote capture, AUVs, UAVs, videography, imagery;
- Capture: in-situ, remote, physical, semi-autonomous, autonomous, immersed, sensors;
- Reliability: Verification, validation, error;

- Data Integration;
- Spatial Statistics, analysis and outputs; and
- Dissemination imperatives.

The SIntegraM (European Commission, 2020) and SpatialTrain (European Commission, 2019) initiatives sought to lay the groundwork for this process, which further require impetus on the transformation parameters required from the spatial domains. These include:

- Real-World to Virtualisation and Visualisation Processes;
- Analytics – tools, software, data mining, deep learning, BIG data, open data, impact analysis;
- Legislation, directives, Data Protection, DPIA, financials, auditing, security, National Data Strategies, Smart Specialisation Strategy, RRP and other instruments;
- Reporting;
- Disseminators – IoT, real-time analytics, gaming, metaverses;
- Real-World to Virtuality Interactivity;
- Digital Twins – replication, innovation;
- Immersion; and
- Inter-Domain/Entity/Industry/Academia/Governance/Stakeholder collaboration: specifically, the domains catering for AI, Built Environment, GeoSciences, ICT, Social, Public Sector, Public Service, Industry

Sourcing the Protocols

The imperative of the digital transformation impinges on the need to be aware of the INSPIRE parameters as well as the GDPR requirements to ensure that any data pertaining to individuals is removed to ensure privacy (European Parliament, 2012). This section partakes to the descriptors of such a process that detail the reasons for conducting a DPIA, the nature, scope, context, and purpose of the envisaged processing, the procedures employed, the processing operations, the legal basis for processing, the categories of personal data processed, resultant security of processing, retention, data subject rights, and risk assessment. The process to capture data and ensure protection is difficult in spatial technology processing due to the sheer volumes of data being captured on a routine basis. aerial, terrestrial and bathymetric data is volume and space hungry, requiring additional tools to ensure protection on all levels.

As a case study the chapter describes the process required to capture spatial data for digital transformation using aerial technologies such as UAVs.

- **Reasons for conducting a DPIA**: main reason pertains to a new processing activity for the update of the specific thematic map for the Maltese Islands.
- **Description of the nature, scope, context, and purpose of the envisaged processing**: upgrading the national spatial data infrastructure developed through the SIntegraM project with the scope of enhancing the capacity of geospatial and GIS expertise in Malta. The thematic map processing activity subject of the DPIA involves the capture of a thematic map such as an erosion map, a water stream flow analysis. This update process is in line with the relative legislation and seeks to undertake the functions mentioned in the relative legislative tool empowering the data cycle. It is imperative that the DPIA details that the process will be repeated every nth-year cycle.
- **Procedure for the capture and processing**: To define type (such as aerial imagery), means (capture technologies such as drones), locational parameters (distance, height, range as per applicable legislation).
- **The protective measures**: Definition of what could be captured such as 3D pointclouds or images of persons or vehicles within range of the data capture exercise, the processing methodologies, the scope of the exercise, the responsible parties, the data cycle description inclusive of design, capture, cleaning, analysis, outputs and dissemination. The technologies (hardware and software) employed in the process need to be defined as well as the processing methods employed to reduce the pointcloud and image definition, where clouds are trimmed to ensure protection and where images of persons are blurred.
- **Legal basis for processing**: description of the law within which the exercise is conducted.
- **Categories of personal data processed**: description of persons, property, facial elements, and other items that may be captured are to be detailed.
- **Security of processing**: description of how data is stored (cloud, hard-disks, SD cards). Retention and hardware reuse, restricted access, detail that the data is not made available to third parties. Detail of the tools employed such as those listed in the tools section below and how they are used to reduce pointcloud and image definition. Retention periods require stipulation.
- **Data subjects rights**: detailing of how the spatial data organiser will inform the public of such as exercise. This includes informing residents through advising the respective Local Council of the dates and times of technology operations, advertise the relative entity website and social media of the operation's locality, dates and operating times, publishing through the Government Gazette as well as inform residents in-situ through visible signage close to the area of the technology operation to inform passers by of the processing activity.

- **Risk Assessment**: Detailing of the risks emanating from such an activity inclusive of the threat and subsequent residual risk of infringing data protection rights.

Technologies In hand

Diverse technologies are employed in this exercise which cater of aerial, terrestrial and bathymetric domains as well as subterranean and ground penetrating exercises. Urban and rural open spaces have been captured using UAV (Unmanned Aerial Vehicle) and Laser Scanning technologies (Figure 1), as well as TLS (Terrestrial Laser Scanner). The technologies employed included aerial systems inclusive of DJI Mavic Pro 3 AUV (imagery – Figure 2), DJI INSPIRE (imagery), DJI M200 (imagery, infrared) DJI M600 Pro (imagery, infrared, GPR), and a RiEGL RiCOPTER (LiDAR, imagery, infrared). In terms of legged robotic technology, a Unitree Go1 Ai Pro Robot was acquired for scanning in difficult areas such as tunnels and caves, which aided the earlier Faro Freestyle Handheld scanner and the DJI Osmo.

In terms of terrestrial and mobile technologies, the researchers used a RiEGL VZ400i Terrestrial Laser Scanner (LiDAR, imagery) and a GreenValley LiBackpack50 (LiDAR) as well as the RiEGL Vehicle-based VMX-2HA system (LiDAR, imagery). Access to a bathymetric Gavia AUV (autonomous underwater vehicle and a tethered QYSEA FIFISH V6 Underwater Robot. Software used in the processes included Reality Capture, Zephyr 3D, Agissoft Metashape, Pix4D, Lidar360, RiScanPro and RiProcess. Output software that was used for scene reconstruction and immersion analysis include Unity 3D and the MagicLeap applications, whilst the WebGL outputs were published using LasPublish as published on www.cloudisle.org.

Figure 1: Plane based pointcloud

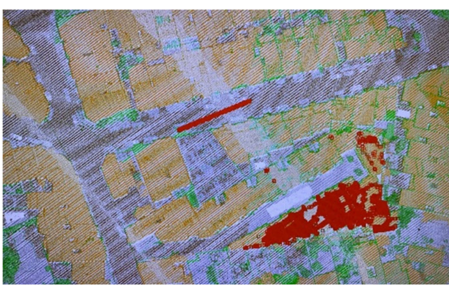


Figure 2: Imagery

Challenges to visualise the results

Policymakers and decision-takers face a challenging duality: their internal visual recollections of what should be and the visualisation they must partake to understand that which is. The discord between flat-photomontaged landscape perception and immersive 3D environments is gradually enabling decisions to be taken within an integrated data-information-knowledge approach. In addition, with a spatial checking process overlaid over a plane-based LiDAR nadir data layer, the latter's nadir lacunae are compensated for by the drone's oblique ability.

In an attempt to create visually realistic scenes for decision taking, a study governing an entire data cycle was attempted to understand the creation of a rolling data capture enterprise for quasi-real-time data capture and outputs. Mapping landscapes through photogrammetry, laser-mapping and GPR were attempted through a conceptual view to creating substantially detailed models that could be modelled in a 3D environment that enables users to explore otherwise unavailable landscapes (Lovett et al, 2015). The porting of such outputs to other domains such as offender studies (Formosa Pace, 2014), offence studies (Formosa, 2007), crime scene generation, inaccessible spaces analysis (Obanawa et al, 2014), erosion studies and heritage outputs during covid-19 closures proved the affectivity of such processes (Bustillo et al, 2015)).

Creating 3D models actually transcribes the final aspect of the data process, with the major activity employing an entire mission planning to fly drones, ground control activities, photogrammetric processes, laser scanning, integration and model exporting. Data capture technologies used include UAVs, AUVs, terrestrial laser scanners, mobile laser scanners, GPR and real-world in-situ human-painted GCP anchor markings. Flight plans were affected through Drone Deploy path mapping averaging 20,000 images per town anchored through 80-100 GCPs as loaded into photogrammetric tools, mainly Agisoft Metashape and more recently Reality Capture. The resultant dense clouds, meshes orthoimagery and DTMs were exported for visualization use (Figure 3).

Laser-scanned areas were also employed through Riegl's Vzi400 and the Mobile laser scanner particularly during the covid-19 enforced empty streets that enables street-level drive-through scanning. Riscanpro and Riprocess enabled the generation of pointclouds and simple meshes for further visualization outputs. Data visualization in immersive environments was enabled through the resultant rendering of the 3D models generated in Unity 3D for the 7-panel CAVE (Computer Automated Virtual Environment) (Li, 2020) (Figure 4), Oculus Rift and Magic Leap (Manjrekar et al, 2014; Yoon et al, 2015). The exporting of same models to an interactive executable (.exe) application has enhanced the outputs to enable users to revisit the scene from a desktop of mobile device.

Figure 3: The image to Information process: LiDAR-DSM-Vector-3D

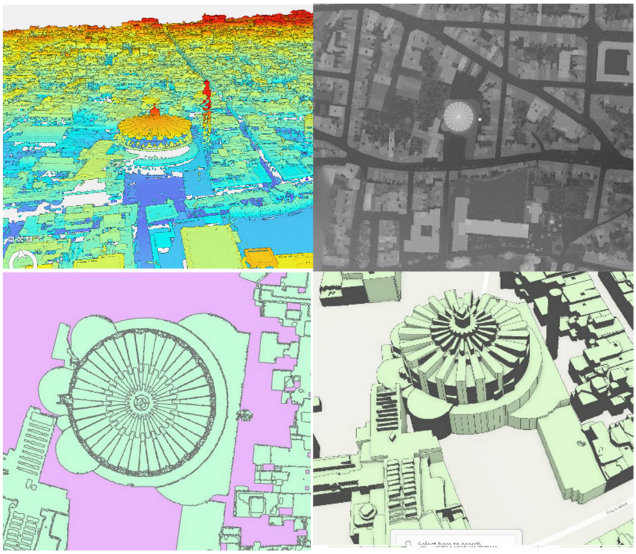
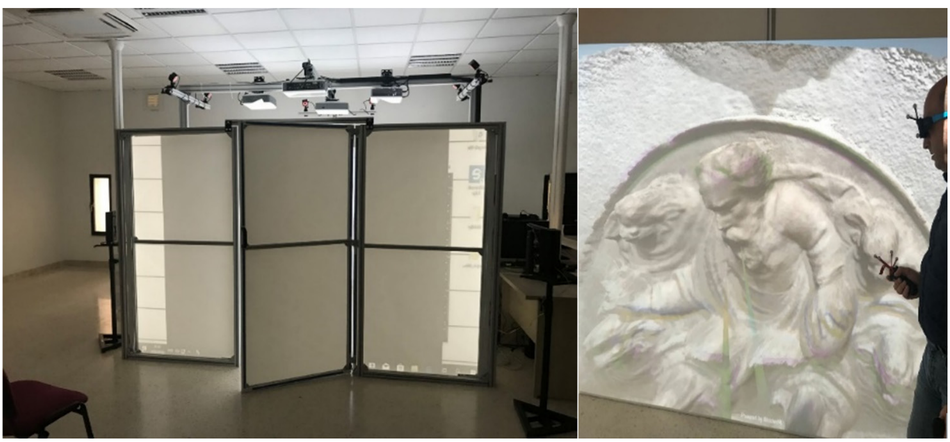


Figure 4: Reaching an immersive level through a CAVE environment



Dissemination

The use of Immersive technologies in understanding past-present and potential landscapes was crucial in understanding how best to preserve a medieval city (Figure 5), to study the changing townscapes in ribbon development in a second island, and to understand how erosion was instrumental in the deterioration of coastal zones and its impact on tourism, calculating quarry rehabilitation volumes as well as monitoring a major sinkhole in a world heritage site. In addition, the same methodology was employed for the creation of sub-cliff dangerous caving-in phenomenon that allowed interveners to view the extent of the dangerous structures in a safe and immersive lab environment (Figure 6).

Taking the technology to the next step through the visualisation of the areas under study is achieved through the rendering of 3D geolocated immersive environments that can be used by landscape designers, architects and decision takers once again on site through the visualisation of the was-is and will be based on their lon-lat coordinates.

Figure 5: 3D medieval city generation for eventual immersion studies

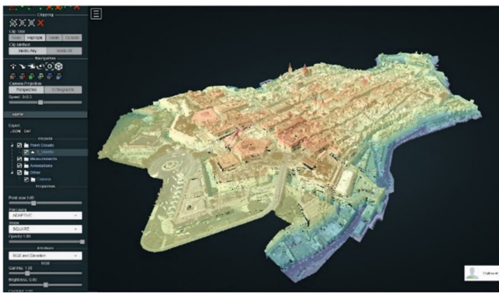
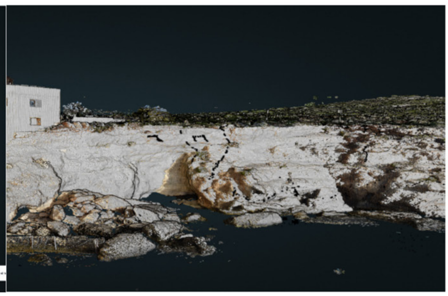


Figure 6: Cliff-side dangerousness studies



Source: www.cloudisle.org

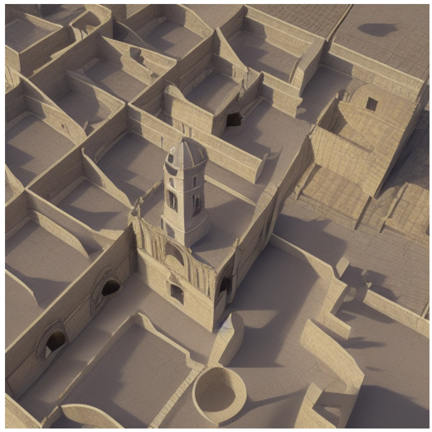
The Next steps to aid Visualisation: AI and AI image generators

Visualisation and its employment for environmental, social, psychological and other multi-discipline domains has recently become challenged by outputs being generated through AI art renderers that replicate/mimic/create outputs similar to those generated by the processes mentioned in this paper (Gao, 2021) (Figure 7). The challenge for researchers over the next period will be to empower the spatial domain through the integration of such tools to enable deep learning of the methods used to understand the physical, social and natural environments such that the power that these tools have are harnessed for the empirical research process, the operational aspects as well as the search for elements that human eyes may not capture but such tools do.

The jump from physical maps to 2D GIS layers to 3D pointclouds and meshes to immersive technologies has offered breakthrough for domains linked to a locational imperative. The use of enhanced tools to identify alternative or as yet hidden elements in spatial analysis would only enhance the outputs, always within the parameters of the digital transformation, protocols and protection levels detailed in this chapter (Figure 8). The use of technology to capture ever defined resolutions is paralleled by hi-end analytical and visualisation tools that will push spatial information towards the next transformation in urban planning (Pellegrin et al, 2021; Quan et al 2019).

Figure 7: Aerial imagery generated by AI

Generated by author through AI Art App



Generated by author through AI Art App

Figure 8: Development Planning generated by AI

Generated by author through AI Art App

Generated by author through AI Art App

Conclusion

Technology is as advanced as its users push it to understand the reality around them as well as create processes to enhance the research and societal outcomes emanating from such studies. The chapter defined the baseline elements that comprise spatial information, the digital transformation aspects and the methods employed to enable the visualisation of the outputs resultant from the spatial data cycle. The conceptualization of what constitutes data and information as well as its creation of knowledge goes only as far the innovative user can push the technology, hardware and software towards an understanding of the social constructs. Spatial information has come of age through the visualisation construct and how the user employs and understands the protocols regulating the same data flow.

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CHAPTER 19

Reconstructing Humans Using Photogrammetry

Tram Thi Ngoc Nguyen and Saviour Formosa

Introduction

Digitalisation is a process that creates virtual 3D versions of real-world scenes and objects. Predominantly used for mapping in GIS science (Konecny, 2014), digitalisation technologies have increasingly become integral to many scientific disciplines such as archaeology (Drap et al., 2015), anthropometry (Weinberg et al., 2004), cultural heritage (Kingsland, 2020; Remondino, 2011), and forensics (Formosa, 2022; Gitto et al., 2020), allowing researchers to conduct detailed analysis – directly or remotely - with minimal risks of contaminating the real subjects.

Within the realm of digitalisation technologies, laser scanning technologies have existed for a few decades. However, they remain only within reach of professional entities with large budgets and expertise. Models created by laser scanners are superior in terms of structural integrity and resolutions (i.e., polygon counts), which requires large processing powers to modify and render (Foster & Halbstein, 2014). Recent developments in photogrammetry make it possible for virtually anyone with a camera device and access to commercial photogrammetry software (Stark et al., 2022) to use the technology. This enables idea generation and progress in low-scale projects such as in the case of educational bodies and individual artists. This chapter documents three low-scale projects using photogrammetry carried out at the SIntegraM MAKS Immersion Lab, University of Malta, led by Professor Saviour Formosa, in collaboration with Malta Forensics Lab and Malta Police Force, led by Inspector Charlot Casha. Data collection was assisted by forensics photographer Antoine Fenech. Data processing and dissemination was carried out by research officers Fabrizio Cali and Tram T. N. Nguyen at the SIntegraM MAKS Immersion Lab.

A common theme running across these projects is human-centred reconstruction. In the first project, we reconstructed a skull at the request of St Peter's monastery as part of a forensic project. In the second project, we reconstructed the face of a digital art student whose project was to create wearables. In the last project, we reconstructed the full body of Neil Agius – an Olympian swimmer – at the request of artist Austin Camilleri in his project to forge a 3-metre-high bronze sculpture. These constitute the category of close-range photogrammetry.

As opposed to far-range projects in which a semi-automated drone can be deployed, scanning close-range subjects requires manual execution of a camera or multiple cameras. This poses unique technical challenges (Samaan et al., 2013). Furthermore, progressing from an inanimate object such as a skull to a live subject (faces and bodies) raised the level of technicality required, especially given the constraints on equipment and budget. It is the aim of this chapter to demonstrate the feasibility of photogrammetry and detailed documentation for future attempts in replicating the process. General technicalities such as lighting, camera settings have already been discussed extensively in other literature (Foster & Halbstein, 2014; Linder, 2009). Instead, the chapter focuses on the unique aspects of each scanned subject and the technical solutions involved to achieve desirable results. The next section provides a brief description of photogrammetry techniques. Section 3 describes in detail the projects. Finally, we conclude the chapter with a discussion on future directions.

Photogrammetry: A brief overview

The word *photogrammetry* consists of *photo*, referring to light, *gram*, referring to drawing, and *metry*, referring to measurement. Photogrammetry is the science of measuring distance in three-dimensional (3D) space using photos. It falls within the category of remote sensing technology because measurements and distance analysis can be made without direct physical contact. The simplest example of photogrammetry is the way our brain infer depth, hence 3D perception, using image inputs from our two eyes (i.e., stereoscopic perspectives) (Linder, 2009).

In photogrammetry techniques, multiple photos are taken to capture every possible angle of a subject. A photogrammetry software employs sophisticated algorithms to calculate coordinates of an image feature (a pixel) relative to other features in 3D space – a process called triangulation. Triangulation dictates that each feature must be viewed from at least two different perspectives, hence one of the keys to successful 3D reconstruction is image overlapping. The suggested degree of image overlapping is approximately 50% or images taken from every 5-10 degree in angle (Foster & Halbstein, 2014), although this can vary depending on the characteristics of the scanned subject.

The fundamental principle of feature extraction and interpolation used in photogrammetry means that featureless objects (or parts of objects) are a major problem for a photogrammetry software. This also applies to glossy surfaces, as light can be reflected differently from different angles. These issues lead to incomplete or fractured models ('holes'), a problem we frequently encountered, especially in dealing with live subjects (see Project 2 and 3 for more details).

As mentioned earlier, photogrammetry in far-range projects, such as mapping an area, can be carried out by a drone with an automated function to take interval photos in a grid-like fashion. For close-ranged objects, manual execution of camera devices is often employed. Any human inconsistencies that cause image imperfections (e.g., blurring) can have detrimental effects on the working of photogrammetry algorithms, such as a complete failure in determining the target pixel in each image for triangulation processing. Furthermore, scanning a live subject introduces related, but different, kind of inconsistencies amongst the image sets, due to micro muscular and postural movement of the live subject. That means a given feature changes location between images, leading to double meshing in the final model. Our experience and that of others (e.g., Pesce et al., 2016; Samaan et al., 2013) have proven that systematic procedures to increase feature consistency is a critical contributor to the quality of the final models, among other basic technical considerations.

An ideal scenario of photogrammetry requires absolute removal of human inconsistencies. As such, full-scale automated and streamlined photogrammetry systems have been constructed. For example, the CultLab3D system uses robotic arms, conveyors, and multiple cameras to produce perfect 3D models of important archaeological artefacts (Santos et al., 2017). State-of-the-art scanning systems for full human bodies typically feature a camera rig with multiple high-quality cameras synchronised, so that any posture can be capture instantaneously and simultaneously at all viewpoints. Examples of such systems are the ESPER geodesic system (https://www.esperhq.com/), or the Botscan Neo (https://botspot.de/) which costs approximately $200,000. These professional systems are certainly out of reach for low-scale, educational, research-based, or independent projects, such as the ones carried out at our laboratory.

Nevertheless, several photogrammetry practitioners have attempted to achieve golden standards with ingenious low-cost solutions (Gitto et al., 2020; Iwayama, 2019; Stark et al., 2022, 2022). This is feasible because the quality of the final models is greatly determined by the skills and expertise in maintaining the core principles of the technique, namely consistent image overlapping degrees, lighting, image quality and standardisation. Successful results come from a systematic scanning process in which measures are taken to minimise human inconsistency. The following section goes into detail about the three projects carried out at our laboratory, the technical challenges each scanned subject posed and solutions to achieve satisfactory results.

Project details

In all three projects, we used a combination of a turntable and interval shooting modes. This setup ensured that camera angles were equally spaced and minimised micro movement of the camera as in the case of manual shooting mode (see Thomas et al., 2019 for a similar setup). Care was taken to balance the rotating speed, image clarity, and shooting duration. The final models were reconstructed using RealityCapture with an academic license.

Project 1: Reconstructing Beata Adeodata's skull
Background information

This project was a collaboration between our laboratory and Malta Forensics Laboratory, at the request of St Peter's Monastery, Mdina.

Beata Adeodata was born Maria Adeodata Pisani in Naples, Italy in 1806. Her father was a famous Maltese baron and her mother was Italian. She grew up in an aristocratic household and received a prestigious education from the famous Istituto di Madama Prota in Naples. After her father was sentenced to death due to his involvement in the Naples uprising, she moved to Malta at the age of 19. She became a nun at the Benedictine Community in St. Peter's Monastery at the age of 21. She led a modest and charitable life and was known to be a frail woman with physical and cardiac problems. She died in 1855 at the age of 48 and was buried in the crypt of the Benedictine monastery at Mdina. In 2021, a project to excavate her tomb was carried out. Apart from her skull, the rest of her skeletal remains were almost fully decomposed and unrecognisable. Her skull was reserved and displayed at the main chamber in the monastery. The purpose of this project was to archive her skull digitally and create a physical replica for further forensic research.

Technicality and procedure

A skull is a highly suitable object to photogrammetry due to its maneuverability and detailed featureful surface. One technical challenge of capturing the skull's entirety was to capture self-occluded parts such as the inner bone cheeks and eye sockets (Figure 1b).

Figure 1: a) Depiction of Beata Adeodata; b) Frontal view of the skull; c) Scanning setup.

a) b) c)

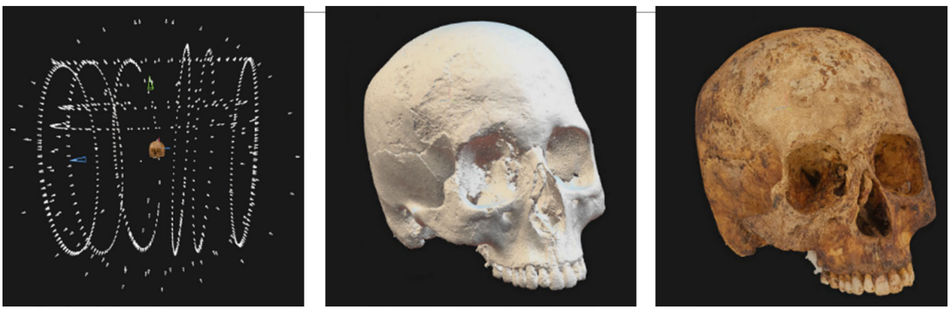
To ensure balanced lighting, the skull and the turntable were placed in a reflective cave with lights surrounding the outside (Figure 1c). The skull was placed at four different positions (upright, sideways, inverted) to ensure every possible angle to be captured. At each position, the camera was set at three different heights to create enough coverage of self-occluded parts.

Result

Figure 2a shows the final model with camera positions estimated by the software. The model was impeccably reconstructed in RealityCapture in the first run with all self-occluded parts captured (Figure 2b), suggesting that our scanning setup was adequate. The textured simplified model is shown in Figure 2c.

Figure 2: 3D model of Beata Pisani's skull. a) Camera positions, b) Solid mesh, c) Textured mesh

a) b) c)



The model was impeccably reconstructed in RealityCapture in the first run with all self-occluded parts captured (Figure 2a), suggesting that our scanning setup was adequate. Figure 2b shows the final model with camera positions estimated by the software. The textured simplified model is shown in Figure 2c.

Remarks

The result of this project highlighted the importance of systematic shooting in photogrammetry techniques, among other basic technical arrangements such as lighting and camera settings. Although there exist post processing solutions that can be applied to problematic datasets (for example, manual alignment using control points), a high-quality dataset can yield a quick and successful model using RealityCapture software (under an hour in this case). The result of this project (i.e., the 3D replica of the skull, available by request at our laboratory) can be used to conduct further forensic research such as facial reconstruction of Beata Adeodata. A topic brought to our attention was that all existing depictions of the nun were largely idealised (Figure 1a), and the monastery expressed their wish to recreate her face, humanising a real religious figure. This is a real possibility which has been extensively studied in the domain of forensic facial reconstruction literature (Wilkinson, 2004). The resulting 3D model can enable experts in this field to attempt reconstruction both by traditional clay sculpting techniques (Manley et al., 2002) and computerised modelling (Lindsay et al., 2015).

Project 2: Reconstructing a face

Background information

Gabriel Joseph Chetcuti is a digital art student specialising in sculpting wearable face masks using thermoplastics for his dissertation titled Cyclical Constructs. He approached our laboratory to help create a 3D model of his face, to be used in his dissertation project.

Technicality and procedure

As mentioned in the introduction, reconstruction of a live subject is challenging in photogrammetry because of natural micro movement. This has led to the creation of camera rigs that capture 360 degrees viewpoints simultaneously. Without such equipment, the subject must maintain static during the whole shooting period. We fine-tuned the setup so that the shooting duration was as quick as possible, which was more than one minute. One technical challenge of this project was that the skin around the nose was featureless and semi-glossy. To overcome this, we placed face markers over the nose to improve feature detection (Figure 3a). Because we aimed to capture the shape of the face only, one camera set at one height was used.

Result

Figure 3: a) Markers were placed on Chetcuti's nose to improve feature detection within this area, b) Final mesh consisted of 3.5 million polygons, note slight deformation around the top part of the nose, c) Final textured mesh. (with permission from Gabriel Joseph Chetcuti).

Figure 3: a) Markers; b) Mesh; c) Textured Mesh

a) b) c)

Figure 3b showed the untextured mesh of Chetcuti's face. It was evident that the lack of features around his nose was not completely compensated by the face markers. RealityCapture detected marked lines sufficiently to preserve the shape of his nose but failed to estimate the surface between the lines, resulting in some deformations. Nevertheless, the result was satisfactory for the purpose of his project.

Remarks

The project demonstrated how 3D scanning can be made accessible in educational settings. The process was quick, and the result was reasonable to assist students in pursuing their academic projects.

Project 3: Reconstructing Neil Agius's whole body

Background information

Neil Agius is a Maltese former Olympic swimmer and an anti-pollution activist. On 30 June 2021, Agius swam a total of 125km from Linosa to Gozo in over 50 hours, breaking the world's record for the longest non-stop unassisted swim in open water. The record was a symbolic achievement to raise awareness of sea pollution, expressed by his team "If Neil can swim for two nights and two days, no stopping, no getting out of the water WE CAN ALL pickup six pieces of plastic and do a few reps of exercise." (Times of Malta, July 2021).

One month after this nationwide famous event in August 2021, artist Austin Camilleri embarked on a grand project to forge a 2.6 metre and 266kg bronze statue of Agius as the centre piece for his solo exhibition LE.IVA Anger is a lazy form of grief (Martinez et al, 2022). Camilleri sought to finish the project within six months, so that the statue could be exhibited while Agius' campaign messages were still fresh in the public consciousness. This was an extremely ambitious goal, given that a normal process to cast a bronze statue of this scale, especially of a human subject, can take years. To realise this project, Camilleri approached our laboratory to create a 3D model of Agius to accelerate the process of making the cast.

Technicality and procedure

With the same challenges posed by scanning a live subject (see Technicality and procedure, Project 2), scaling up a scanning procedure from a small region (e.g., face) to a whole body brought about new challenges. In terms of the subject, Agius had to maintain a still whole-body posture throughout the process. In terms of technical setup, we had to cover his whole height while maintaining an adequate degree of image overlapping with minimal shooting time. The longer it took to scan, the more posture micro movement would be introduced. For this reason, in the initial scanning session, we opted to use video shooting with the camera revolving around the subject in multiple loops distributed according to his height. However, the initial result was not adequate due to the instability of the chosen posture and the low quality of images extracted from a video

We decided to return to the method of using a turntable and interval shooting setup, which required multiple cameras for height coverage. We were able to arrange these additional cameras through the help of the Malta Forensics Laboratory. Forensic photographer Antoine Fenech oversaw the setting up and monitoring of the cameras (see Figure 4 for the setting up process). Because these cameras have different sensors and lenses, care was taken to ensure that white balance was consistent across all cameras. Fine-tuning the setup took us approximately four days.

Figure 4: Scanning setup overseen by forensic photographer Antoine Fenech

Similar to the face of Chetcuti (Project 2), the featureless whole-body skin was a major issue in photogrammetry, to which we again resorted to using body markers (Figure 4).

Result

Figure 5: 3D model of Neil Agius. a) Camera positions, b) Solid mesh, c) Bronze statue

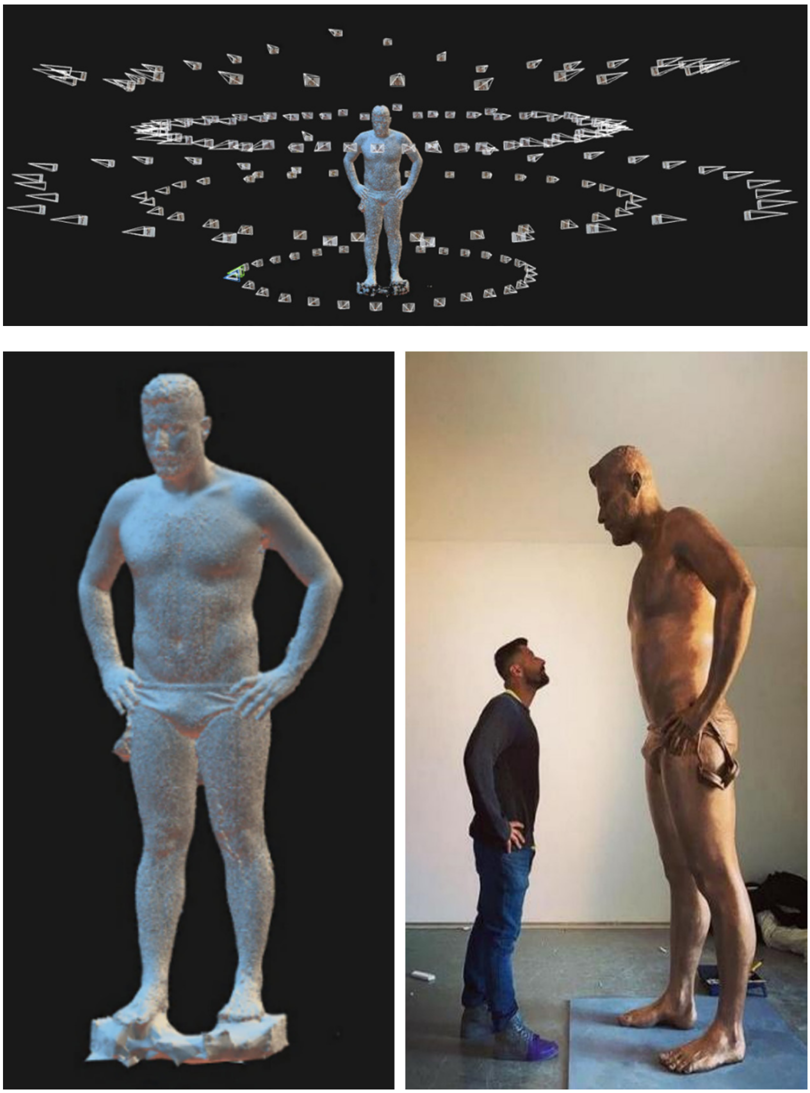


Figure 5 shows the model from the final scanning session using a turntable and multiple cameras set in interval shooting mode. We had to find a good posture for him to maintain balance and stillness on the turntable, this choice resulted in an adequate model (Figure 5b). Although this is a limitation of our setup, the chosen posture has a personal meaning to Agius, as he stood meditating at the ocean before embarking on his strenuous swim. The artist used this scan to 3D print model, enlarge and detail it manually in wax before the lost wax bronze casting process. Figure 5c shows the exhibition of his statue at Spazju Kreattiv in Valletta in February 2022, exactly six months later, as artist Austin Camilleri aimed for.

Remarks

Reconstructing the whole body of a live subject is the ultimate challenge to those who pursue close-range photogrammetry. The project proved that constraints on time, budget, and equipment can often lead to innovative solutions. It also confirmed that photogrammetry is a feasible technology to use for small-scale independent projects. To our satisfaction, this work has become a useful tool to assist contemporary artists like Austin Camilleri, as well as Neil Agius's effort to raising awareness about an urgent global issue. In Agius's own words, "I was taken aback by this feeling of knowing that this statute, this legacy will be here long after I'm gone. It also hit home that the choices we make to protect our sea, and our planet go well beyond us. The choices we make today will have an impact on our children's future and on our planet - a legacy that will last beyond our lifetime." (Facebook post, February 2021).

Future directions and conclusions

One important aspect that we did not control throughout these projects is the degree of accuracy of the models in relation to the actual physical subjects they represent. As mentioned before, because photogrammetry is a remote sensing technology, unlike laser scanning technology, structural accuracy depends greatly on the combination of various factors including the quality of the inputs, the systematic procedure, and the algorithm employed by photogrammetry software. Therefore, whenever structural accuracy is essential, it is advisable to employ laser scanning or combine laser scanning and photogrammetry. The latter option can maximise the strengths of both technologies to produce models with high structural fidelity provided by laser scanning inputs and high-quality textures provided by photogrammetry images. Having said that, recent research has shown that the margin of error can be reduced drastically in photogrammetry with the right setup (deviations under 1mm Katz & Friess, 2014; deviations ranging between 0.01 and 0.02mm Pesce et al., 2016).

Secondly, our current available equipment limits the types of posture to be captured successfully and requires the scanned subjects to maintain stillness for the whole scanning period. Such limitations can be overcome by using extensive camera rigs as seen in large funded commercial projects. We can achieve this standard to a certain degree with lower budget requirements by using inhouse designs and low-cost but more versatile camera modules such as the Raspberry pi camera modules (refer to Iwayama, 2019 for such an attempt). This would semi-automate and streamline the process, allowing any possible posture to be captured instantaneously.

In conclusion, the projects described in this chapter demonstrate that photogrammetry is a viable solution to reconstructing inanimate and live human 3D models. It is especially compelling for those who have constraints on budget and available equipment. The final products can enable further research without contamination of the original subjects (Project 1), as well as extend artistic boundaries and provide added social values for such endeavours (Project 2 and 3). Future research developments in photogrammetry setup, for example, incorporating the element of portability in a camera rig, would open the possibility to work on projects in which scanned subjects cannot be moved, for example, large collections of archaeological artefacts or onsite forensic evidence.

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EPILOGUE

Space within Space

Timmy Gambin

To speak of a ‘digital world’ project is the idea of two parallel realties – the ‘real’ world and the digital or virtual ones. In 2022, this distinction is not only erroneous but also very dangerous. Erroneous because the real and the digital-virtual worlds are so intricately linked that it is impossible to imagine a modern world without the plethora brought about by simply translating basic daily staples such as images, words and music into a series of ones and zeroes. Dangerous because decisions taken today impact future generations and, as this volume clearly demonstrates, the future can be a better place with the benefits brought about by the digital revolution. But what about making the invisible visible?

One small but very tangible example was revealed during the recent COVID pandemic. This example stems from the fields of education and cultural heritage – specifically underwater cultural heritage. This example does not just refer to the technologies specifically developed, adapted, or simply utilized specifically to manage and fight the pandemic. Just as with many sectors, the pandemic was very tough on the cultural heritage sector. Museums were shut down, staff laid off and much-needed fieldwork and restoration projects postponed or cancelled completely. A situation that at first glance seemed completely hopeless, presented a series of opportunities.

- Closed museums provided the perfect opportunity to scan and digitize objects and collections that are otherwise untouchable. Untouchable because they form the core of collections and are one of the reasons why people pay an entrance fee. Many museums, including those run by Heritage Malta, undertook the scanning and digitization of objects that are displayed as well as others from the reserve collection. These were initially done using an ARTEC Leo handheld scanner with data processed on Artec’s propriety software ARTEC Studio. Scanning was executed on site, data transferred online. Data processing took place overseas where a team member was caught in lockdown and subsequently uploaded onto Sketchfab, where a researcher annotated the objects (remotely) before making these available to the public. Besides making objects accessible via the world wide web, Heritage Malta produced over 500 digital models – a digital record that could be used, shared, admired and enjoyed remotely.

- If people cannot go to the sites, then it is imperative that heritage managers take the site to the people. Gozo's coastal towers and gun batteries were all scanned and shared during the pandemic – enabling people to explore these fortifications from the comfort of their home. 3D photogrammetric surveys were carried out using a DJI Mavic pro drone. Images were obtained during repetitive circular flights around the structures as well as cross lines to ensure overlap. Data processing was done using Agisoft Metashape and annotations done on Sketchfab. These towers and gun batteries are exposed to severe weathering and are periodically restored. The simple approach to 3D photogrammetry provides heritage managers and conservators with an easy and affordable solution for recurrent surveys that serve as baselines for future conservation interventions and management plans.

- Underwater archaeological sites are only accessible to those qualified in SCUBA diving. Deep water archaeological sites are reachable to an exclusive group of highly trained and experienced individuals qualified in technical diving. However, there should be no distinction between sites on land and those underwater – at whichever depth these may be situated. To overcome the barrier that is the water column, Heritage Malta and the University of Malta combined forces to create and launch underwatermalta.org – a virtual museum that showcases 20 underwater sites. This initiative is in line with UNESCO's best practices as propounded in its 2001 Convention for the protection of underwater cultural heritage: state parties are to "encourage responsible and non-intrusive public access to underwater cultural heritage in accordance with Articles 2.5 and 2.10 of the Convention." To populate the museum, teams of technical divers developed innovative recoding techniques that enabled the production of 3D photogrammetric models of sites that range from a cold war airplane to a 2700-year-old shipwreck. Site sizes ranged from 12 meters to 150m long and depths varied from 38m to 115m deep. Visitors to the virtual museum can not only experience the sites via standard videos and photographs but also through interactive 3D models and virtual reality.

- One of the most state-of-the-art methods of communicating the underwater world to a 'dry' audience in the post-pandemic world is through videos shot in 3600 with specialized cameras such as the Boxfish and the Insta360 with an Easydive housing. Heritage Malta recently launched its Dive into History 360 outreach campaign. Audiences are given short briefings about the sites they are about to experience. Members of the audience are then asked to put on VR headsets through which they can watch an omnidirectional (and annotated) video of a particular wreck site. Following the video, the audience engages with speakers

> in what is in essence an audience-led discussion. In the long run 3600 videos will be made available to a broader audience with educators able to download these videos and share them with their own audiences.

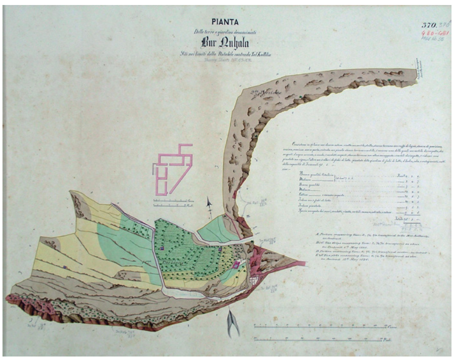
Over recent years, several tools for data acquisition, processing and sharing have become available and are radically changing the ways we communicate with audiences interested in underwater cultural heritage. Although underwater cultural heritage is often considered to be out of sight and therefore out of mind, it is through spatial and digital data that the underwater world has become shareable and available to a global audience.

COLOUR IMAGERY

This section depicts colour versions of selected images from the chapters

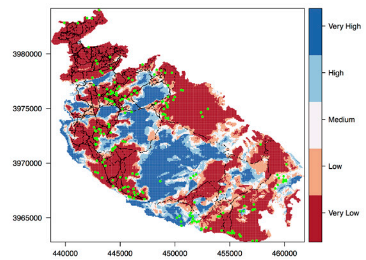
Chapter 1

Figure 1. Example of cabreo map



*Courtesy of the National Archives in Malta; first published in A*lberti et al., 2018.

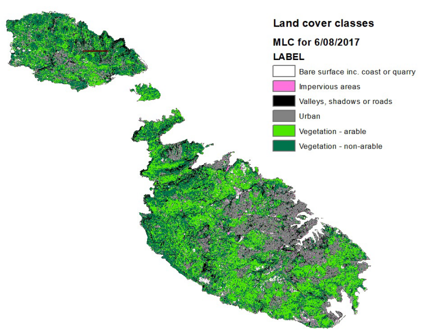
Figure 4. Fitted agricultural quality model for the entire Maltese landscape



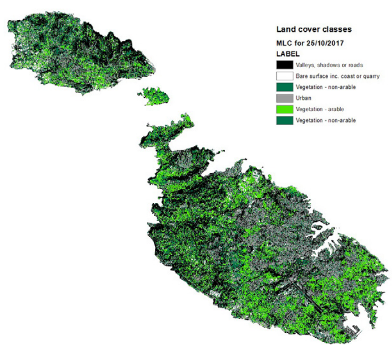
Chapter 5

Figure 5: Land cover classification maps derived for (a) 06/08/2017and (b) 25/10/2017

(a)

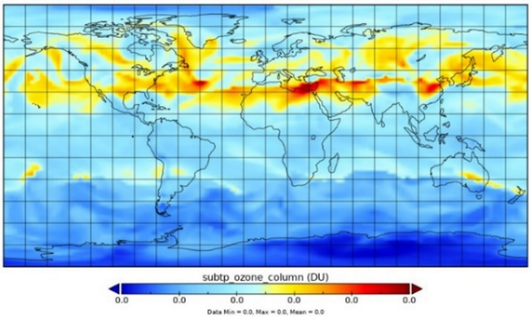


(b)



Chapter 7

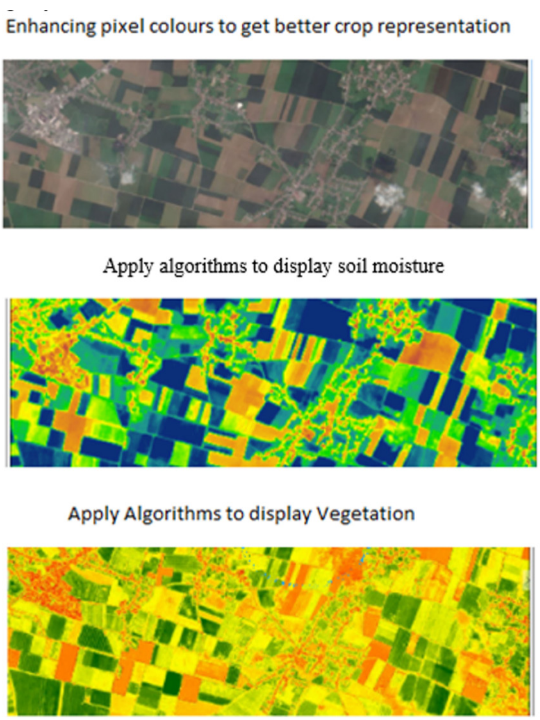
Figure 1 World Tropospheric Ozone Column



Source: Copernicus.org

Chapter 9

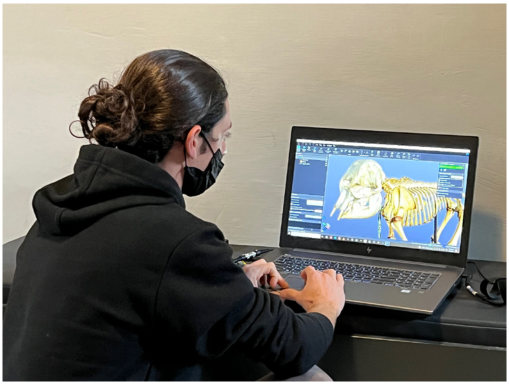
Figure 3: An example illustrating key steps in identifying patterns in satellite imagery



Source: MCAST (2018)

Chapter 12

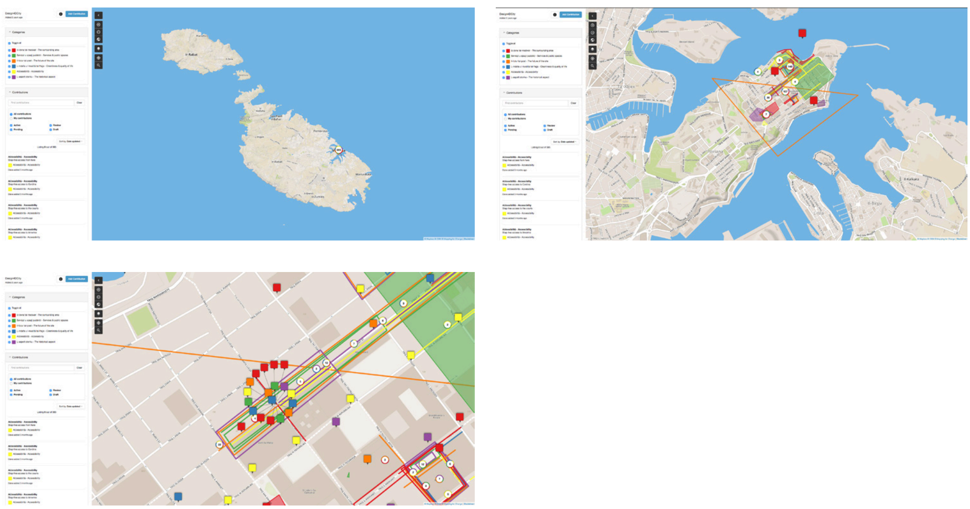
Figure 4: Post processing a laser scan of a baby elephant to create a 3D model of the artifact



Source: Heritage Malta

Chapter 13

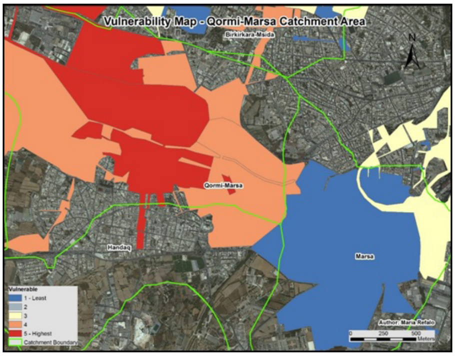
Figure 9: Screen captures of the Mapping for Change platform showing the contributions at varying scales

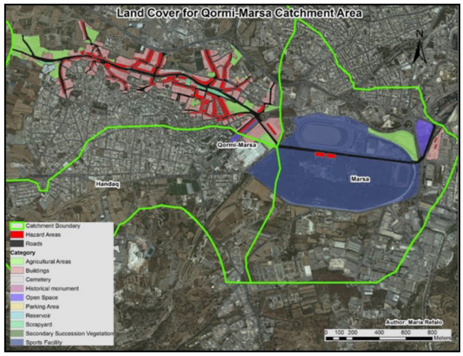


Chapter 14

Figure 9 - Land Cover for Qormi-Marsa Catchment Area

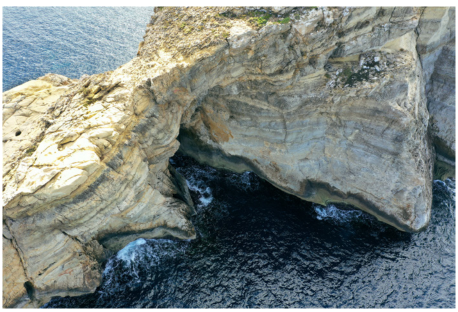
Figure 10 -Vulnerability Map of the Qormi-Marsa Catchment Area





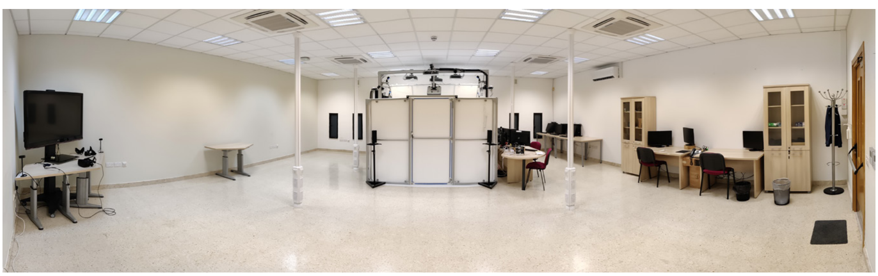
Chapter 15

Figure 2: Fungus Rock, aerial view



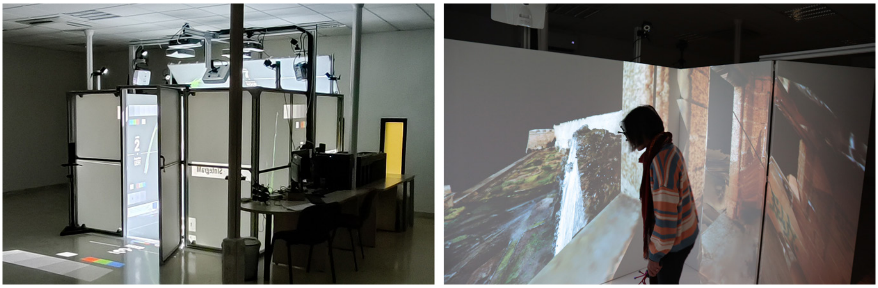
Chapter 16

Figure 1: The MaKS Immersion Lab at the University of Malta



Source: Calì (2021)

Figure 2 The SIntegraM C.A.V.E



Source: Calì (2021)

Chapter 17

Figure 1: A screenshot of the game showing the user's choice whilst a Dog (on the left) and a Woman (on the Right) are crossing the road

Chapter 18

Figure 7: Aerial imagery generated by AI

Generated by author through AI Art App

Generated by author through AI Art App

Figure 8: Development Planning generated by AI

Generated by author through AI Art App

Generated by author through AI Art App

Chapter 19

Figure 1: a) Depiction of Beata Adeodata; b) Frontal view of the skull; c) Scanning setup.

a)

b)

c)

Virtualis
Social, Spatial and Technological Spaces in Real and Virtual Domains
SpatialTrain III

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Virtualis: Social, Spatial and Technological Spaces in Real and Virtual Domains

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Virtualis
Social, Spatial and Technological Spaces in Real and Virtual Domains
SpatialTrain III

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