Organized by

Dipartimento di Pianificazione Design
Tecnologia dell'Architettura

Sapienza
Università di Roma

Coordinated by

Centro di Ricerca
Interdisciplinare Territorio
Edilizia Restauro Ambiente citera

Sapienza
Università di Roma

Supported by

IURC
INTERNATIONAL URBAN AND REGIONAL COOPERATION

A European Union
Programme

International partner

To download the book
for free, scan the QR code

Contacts : www.gis-bim.eu

ISBN 979-12-210-5546-7
9 791221 055467

ISS GIS BIM Lectures and notes for a digital integrated design 2023

GISBIM
INTERNATIONAL
SUMMER SCHOOL

Lectures and notes for a digital integrated design

2023

Fabrizio Cumo
Flavio Rosa
Maria Cairoli
Tommaso Empler
Georgios Kapogiannis
Marco Mari
Athena Moustaka
Jolanda Patruno
Mario Rossi
Nurtati Soewarno
Wikan Danar Sunindyo
Sisi Tan
Claudio Tomazzoli
Claudia Zylka

This text is the result of the international collaboration activities that the CITERA Sapienza University of Rome interdepartmental research center has carried out in Italy, Indonesia, and China, thanks to the European program IURC International Urban Regional Cooperation from 2019 to 2023. The CITERA center coordinated the fourth edition of the International Summer School GIS-BIM for an integrated design promoted by the Department of Planning, Design, Technology of Architecture Sapienza University of Rome.

The Digital Twin, starting from the vast scale of GIS up to that of the architectural details of BIM, is no longer just a revolution in the built environment sector but a continuous innovation process for all technical-scientific disciplines applied to architecture. It is a path in which it is necessary to find, develop, and grow cross-cutting and multidisciplinary activities for today's students who will be the professionals of the future. The CITERA center and its community of teachers and researchers have for years been committed to sharing the results of research on innovative methodologies and organizational structures in the digital transition of architecture at a national and international level.

This text contains the lessons held by teachers from all over the world during the fourth 2023 edition of the Summer School which was held under the scientific direction of Prof. Fabrizio Cumo and the coordination of Prof. Flavio Rosa. The lessons presented in this book take the form of scientific papers, which discuss the theme of this fourth edition: the theory and practice of the Digital Twin applied to the built environment. They draw on academic research or the professional experience of individual teachers and provide in-depth analysis on the historical architectural heritage, along with integrated GIS and HBIM solutions.

GISBIM 20 23
INTERNATIONAL
SUMMER SCHOOL

Lectures and notes for a digital integrated design

Organized by

Dipartimento di Pianificazione Design
Tecnologia dell'Architettura
SAPIENZA
Università di Roma

Coordinated by

CITERA Centro di Ricerca
Interdipartimentale Territorio
Edilizia Restauro Ambiente
SAPIENZA
Università di Roma

Supported by

IURC
INTERNATIONAL URBAN AND REGIONAL COOPERATION

A European Union
Programme

International partner

Institut Teknologi Bandung
1920

柳州城市职业学院
Liuzhou City Vocational College

Lectures and notes for a digital integrated design

2023 International Summer School

GIS and BIM

Department of Planning, Design, and Technology
of Architecture (DPDTA)
Faculty of Architecture
Sapienza University of Rome

Rome July 17-29 2023

Scientific board

Flavio Rosa

MSc in Environmental Engineering and Land Management Faculty of Engineering Sapienza University of Rome. Qualified engineer registered in the register of the province of Rome. PhD in Energy at the Department of Nuclear Engineering and Energy Conversions (DINCE) Sapienza University of Rome. Adjunct professor in Environmental Building Physics Faculty of Architecture of Rome since 2014. Formerly professor at the 1st level University Master's Degree in BIM, Building Information Modeling, Faculty of Architecture Sapienza Rome, and 1st level Master's Degree in Building Process Management - Project Management. Research fellow at the CITERA Sapienza University of Rome research center for the "Sun4U" project Empowering and Sharing Tools to Enable Renewable Energy Communities (REC) in Rome. Author of numerous publications in the field of renewable energy and energy requalification in modern and historic buildings. Responsible for international relations of the SAPIENZA CITERA centre. Expert-advisor to the IURC Australasia program for university cooperation projects on positive energy districts, energy communities and Digital Twin solutions for the built environment. Visiting professor at the Faculty of Engineering of the Universidad Tecnologica de Panama (UTP) on Digital Twin solutions for the built environment. Coordinator of the International Summer School GIS and BIM for integrated design, Department of Planning, Design, Architectural Technology Sapienza University of Rome from 2019 to today.

Federico Cinquepalmi

Prof. Federico Cinquepalmi (PhD) holds a degree in Architecture and Planning from the IUAV University of Venice – Italy (1994) and a PhD in Science and Technology for Industrial innovation from the Sapienza University of Rome (Italy). Since March 2022 is full professor of Project Management at the Faculty of Architecture of Sapienza University in Rome, and is serving as Chair of the bachelor's degree in Project management. Previously since 2009 to 2022 he was senior researcher at Italian National Agency for new technologies, Energy and Sustainable Economic Development (ENEA) and Italian National Agency for Environmental Protection and Research (ISPRA) and in the meantime was appointed as Director of international affairs at the Ministry of Universities and Research of Italy. In the last 30 years he focused his scientific attention in the sectors of sustainable development and policies applied to build environments, digital technologies for building management and cultural heritage. From 2009 he was seconded at the Italian Ministry for Education University and Research (MIUR) as Director of the office for the Promotion, Programming and Coordination of International Research and since April 2015 to March 2022he has been appointed Director of the Office for Internationalization of higher education, a new position created for joining international activities of universities and art and music institutions. In the last 25 years of research activities he focused his scientific attention in the sector of sustainable development and policies for energy and environment, with special regard to Digital and Technological support for Built and Natural environments. His scientific activities were mainly developed at: IUAV University of Venice (Italy), Venice International University; Italian National Research Council (CNR); US National Oceanographic Atmospheric Administration (NOAA); University of Massachusetts - Urban Harbor Institute of Boston; Washington University, School of Marin Affairs; Cambridge University as Visiting academic at the Department of Geography and Cambridge Centre for Landscape and People (CCLP) and Polytechnic of Tirana. He is author and co-author of about 85 scientific works published in national and international journals and books, but also author of 15 institutional documents, among them the Siracusa Charter on Biodiversity, the National Strategy for Biodiversity in Italy, and the national policy framework related to the Ageing society. In 2013 he has been received as active member for the class 6 (Technical and Environmental Sciences) of the European Academy for Science and Arts. He is also member of the editorial board of the Journal Conservation Science in Cultural Heritage; in 2011 he has been nominated as member of the scientific committee of the Italian Society for the Advancement of Sciences (SIPS), the oldest institution in Italy for the Science advancement and diffusion, founded in 1839.

Spartaco Paris

MSc Degree in Architecture at Sapienza University of Rome in 1999. PhD in Environmental Energy Technologies for Development; he has been scholar at ETH in 2003; after teaching at Polytechnic of Bari, he's full professor in Technological Design at Faculty of Architecture of La Sapienza Università di Roma. He's currently Chair of Msc in Project and Construction Management of building systems at Sapienza University of Rome. He develops his research around the topics of new technologies, digital processes, sustainability in the broad area of design, between architecture, built environment and industrial design. Since 2022 is director of CITERA, Interdepartmental Centre of Research Territory, Building, Restoration Environment at Sapienza University of Rome. He has participated in national and international competitions, with significant recognition and awards. He is the author of over 150 scientific publications, including 6 monographs. He has collaborated on the editorial board of Domus, an international architecture and design magazine; he is a member of the scientific committee of the magazine Diid_disegno industriale- industrial design. He is a founding partner of the Sapienza university start-up BEST design srl.

Elisa Pennacchia

Architect, PhD in Energy and Environment from the University of Rome La Sapienza, obtained the National Scientific Qualification as Associate Professor in the field of 08/C1 Design and Technological Planning of Architecture in 2020. Since 2013, she has been consistently engaged in research on topics related to environmental sustainability, energy efficiency, age-friendly technological design, and the digitalization processes of the built environment. She has participated in several national research projects developed through collaboration agreements between the CITERA research center—Interdisciplinary Center for Territory, Building, Restoration, Environment at the University of Rome La Sapienza—and ENEA, the Italian National Agency for New Technologies, Energy and Sustainable Economic Development. She has also contributed to CITERA's research activities within European projects aimed primarily at identifying best practices for energy efficiency in the building stock and sustainable design in protected areas, and at defining the most suitable solutions for the accessibility and usability of spaces at both building and urban scales tailored to longevity.
She is the author of over 70 scientific publications, including 5 monographs.
She is a member of SITdA - Italian Society of Architectural Technology.
She serves on the editorial board of the scientific journal Ponte, a quarterly publication on Architecture, Technology, and Construction Legislation.
She is a founding member of the Sapienza University start-up BEST design S.r.l.

Virginia Adele Tiburcio

Civil Engineer, graduated in 2020 with a degree in Project and Construction Management of Building Systems, an interfaculty Degree Programme between the Faculty of Architecture and the Faculty of Civil and Industrial Engineering, University of Rome La Sapienza. In 2018, she obtained a post-graduate course in Building Information Modelling from the Faculty of Architecture at the same university. PhD in Engineering-based Architecture and Urban Planning from the Department of Civil, Building, and Environmental Engineering at Sapienza University of Rome, with a dissertation that explores the innovation of the Digital Twin concept as an analytical and evaluative tool to support decision-making processes. Currently, Research Fellow at Politecnico di Milano, for the research program called "Standardized digital information flows for public administrations."

CONTENTS

Module 1 - GIS and BIM: Digital Transformation of the Construction Industry

Module 2 - GIS-BIM Theory and practice

Module 3 - Historic Building Information Modelling (HBIM)

Acknowledgments

A special thanks for the continuous and constructive support goes to all the people who made possible the realization of this book and all the other activities connected to them:

The European Union with Alexandra Lehmann and Michel Mouchiroud from the European Union's Foreign Policy Instruments (FPI) Asia team as well as Ramón Lopez and Ronald Hall from the European Commission's Directorate General for Regional and Urban Policy (REGIO).

The Interdepartmental Research Centre for Territory, Architecture, Heritage and Environment (CITERA) with Fabrizio Cumo and Spartaco Paris

The Department of Planning, Design, and Technology of Architecture at Sapienza University with Laura Ricci and Fabrizio Tucci

Foreword

Pablo Gandara
Team Leader EU-funded International Urban Cooperation and Regional (IURC) Asia & Australasia Project
pgandara@iurc.eu

It is a great pleasure for the IURC Asia & Australasia (IURC AA) project team to have been able to support Sapienza University in the preparation of the 4th international summer school on Geographic Information Systems (GIS) and Building Information Modeling (BIM) implemented online in July 2023. The CITERA research centre at Sapienza University has been scientific partner to the IURC AA project throughout the whole implementation 2021-2023, which demonstrates continuity in cooperation since the 1st summer school in July 2020. In Asia, CITERA has also supported the IURC partnership between Regione Lazio and Yangzhou (China), coordinating the corporation between Rome Capital with the Indonesian city of Bandung, and bringing knowledge on blue economy development from the Italian Association of Minor Islands ANCIM to the table.

Managed by the European Union's Foreign Policy Instrument (FPI), the IURC is a programme funded by the European Union that boosts decentralised cooperation between local authorities from EU and non-EU partners in Asia and the Americas in sustainable urban development and regional innovation. The IURC supports the implementation of major international agreements on urban development and climate change, such as the New Urban Agenda, the Sustainable Development Goals, and the Paris Agreement. The IURC grounds on the 'quadruple-helix' approach involving the research community, the business sector and the civil society into the public authorities' cooperation. Since the beginning of the IURC activities in Asia and Australasia, Sapienza University has taken a leading role in bringing scientific knowledge to the partnerships, added great value to the programme.

The 4th summer school on BIM and GIS has again delivered deep insights into urban planning, which is the base for achieving a sustainable urban development. Moreover, for this edition, the Sapienza University team was able to gather a renowned academic team from European and Asian countries. The all contributed cutting-edge knowledge on the use of digital twins for achieving integrated urban design and for retrofitting historic buildings. By providing digital transformation knowledge to international students and practitioners from areas like energy efficiency and architectural heritage protection, Sapienza contributes to promoting sustainable solutions to the construction industry at global scale. This is a remarkable commitment.

From the IURC Asia & Australasia project perspective, I am delighted to see that peer-knowledge from Indonesia and China has been involved in the summer school syllabus. I am also happy to see that the digital platform HYPERLINK "http://www.gis-bim.eu"www.gis-bim.eu remains in place for long-term cooperation between experts from Europe and Asia.

Introduction

Prof. Fabrizio Cumo
Scientific director of the International Summer School GIS and BIM for an integrated design
Department of Planning, Design, and Technology of Architecture (DPDTA) of the Faculty of Architecture at Sapienza University of Rome
frabrizio.cumo@uniroma1.it

It is with great pleasure that I present to you the text containing the articles of the teachers who participated in the fourth edition of the International Summer School GIS and BIM 2023, organized by the Department of Planning, Design, and Technology of Architecture (DPDTA) of the Faculty of Architecture at Sapienza University of Rome and coordinated by the CITERA Center. This publication represents an important testimony of the advanced knowledge and innovative perspectives emerged during the course, highlighting the significant contribution of the teachers who shared their expertise with the participating students. I wish to express deep gratitude to all the teachers who dedicated their time and expertise to enriching the students' education, providing an illuminating overview of the crucial themes of Geographic Information Systems (GIS) and Building Information Modeling (BIM). The diversity of perspectives and the interdisciplinary approach of these experts have undoubtedly enriched the context of the Summer School, offering students a unique and comprehensive learning experience. A heartfelt thank you also goes to the International Urban Research (IURC) for its valuable and consistent support. Collaboration with IURC has significantly contributed to the success of the Summer School, facilitating access to resources and expertise that have further enriched the program. I am confident that reading the articles collected here will offer a thorough and stimulating insight into recent developments in the field of GIS and BIM, consolidating our dedication to promoting research and innovation in these disciplines.

Integrated design for cross-cutting knowledge

Prof. Flavio Rosa
Coordinator and Editor Summer school
CITERA, Interdepartmental Centre for Territory, Building, Conservation and Environment research centre.
Sapienza University of Rome, Italy
flavio.rosa@uniroma1.it

It is with great pleasure that I welcome you to the fourth edition of the International Summer School on GIS and BIM for Integrated Design.
As we embark on this journey, I am filled with immense pride and anticipation, for this event has grown to become a beacon of knowledge, innovation, and collaboration in the realm of geospatial information systems (GIS) and building information modeling (BIM).

The convergence of GIS and BIM has transformed the way we envision, design, and construct the world around us. The integration of these two powerful domains empowers us to bridge the gap between the digital and the physical, facilitating more informed decision-making, enhancing project efficiency, and ultimately improving the quality of our built environment. The synergy between these technologies promises to redefine the future of architecture, engineering, and construction.

The International Summer School has evolved to embrace this very promise. With each passing edition, we have witnessed remarkable growth in participation and a profound impact on the fields of GIS and BIM. It is a testament to the collective dedication and passion of the attendees, speakers, and organizers who have committed to expanding their knowledge and contributing to the advancement of integrated design.

This book, a compilation of lectures and notes from the fourth edition, is a treasure trove of insights, experiences, and wisdom shared by our distinguished speakers, experts, and practitioners. It is a testament to the intellectual and practical depth that this event offers. Within these pages, you will find a rich tapestry of knowledge that weaves together the technical, conceptual, and practical aspects of GIS and BIM integration.

The journey through this book will take you on a remarkable adventure. You will delve into the intricacies of spatial data, explore the potentials of 3D modeling, and understand the power of data interoperability. Moreover, you will witness how GIS and BIM come together to reshape urban planning, infrastructure development, and environmental sustainability. These lectures and notes, a reflection of the passion and expertise of our speakers, promise to inspire and inform.

To the participants of this summer school, I commend your dedication to learning and growing in your professions. Your enthusiasm and curiosity will drive innovation and change in the world. Seize the knowledge contained within these pages and use it as a catalyst to reshape the landscapes of tomorrow.

To the organizers and supporters of this event, thank you for your unwavering commitment to knowledge dissemination and fostering a community of thinkers and doers. It is through your efforts that we have come to cherish the enduring impact of the International Summer School.

As you embark on this intellectual journey through the pages of this book, remember that the future of integrated design is in your hands. The knowledge you gain, the connections you forge, and the inspiration you receive will shape the future of our built environment. Embrace the possibilities, and let this book be your guide as you chart a path towards integrated design excellence.

Institut Teknologi Bandung - Indonesia

Dr. Tutun Juhana
Dean
School of Electrical Engineering and Informatics
Institut Teknologi Bandung (ITB)
tutun@staff.stei.itb.ac.id

Dear Esteemed Colleagues, Professors, and Participants,

It is with great pleasure and enthusiasm that I extend a warm welcome to each one of you to the 2023 International Summer School on Digital Integrated Design, GIS, and BIM held by Faculty of Architecture Sapienza University of Rome, Dipartimento di Pianificazione, Design, Tecnologia dell'Architettura.

As the Dean of the School of Electrical Engineering and Infor-matics Institut Teknologi Bandung, I am honored to witness the convergence of bright minds and experts in the fields of Digital Integrated Design, Geographic Information Systems (GIS), and Building Information Modeling (BIM). This summer school rep-resents a unique opportunity for all of us to engage in collaborative learning, exchange innovative ideas, and explore the cut-ting-edge advancements in these dynamic fields.

Our School has always been committed to fostering a rich aca-demic environment that encourages interdisciplinary collaboration, and this summer school is a testament to that commitment. The fusion of Digital Integrated Design, GIS, and BIM opens new frontiers in research, development, and application, shaping the future of technology in the built environment.

Throughout this program, you will have the chance to learn from distinguished speakers, engage in hands-on activities, and network with fellow participants from around the globe. The knowledge and experiences gained during this summer school will undoubtedly contribute to your professional growth and academic pursuits.

Once again, a warm welcome to the 2023 International Summer School on Digital Integrated Design, GIS, and BIM. I wish this summer school will be a place for exchanging of ideas and the formation of lasting connections that will undoubtedly emerge from this unique educational experience.

Liuzhou City Vocational College - China

Prof. Liu Hongbo Professor
Vice president of Liuzhou City Vocational College, Liuzhou, Guangxi, China

It is with great pleasure that Professor Fabrizio Cumo invite me to join the fourth edition of the International Summer School on GIS and BIM for Integrated Design. In September 2019, I got acquainted with professor Flavio Rosa from the University of Rome in Liuzhou, Guangxi, China. He visited and communicated with architectural engineering and art design at Liuzhou City Vocational College, where I work. He was very interested in the work done by the Guangxi Traditional Village research and protection team led by me. He introduced the new ideas and new technical methods of CITERA Interdepartmental Centre for Territory Building Conservation and Environment, which he carried, in the protection of architectural heritage, as well as the achievements he made. We signed the cooperation agreement between the two schools on behalf of both schools. During 2020–2023, Professor Cumo, with the coordination of Professor Rosa, assisted in holding three online training sessions for our teachers. More than 20 teachers have obtained the GIS-BIM for digital integrated design International Summer School certificate awarded by the University of Rome, jointly promoting the application and promotion of BIM and GIS technology in the field of cultural heritage protection in China. At present, Liuzhou City Vocational College has widely used these technical methods in the application of Dong nationality villages for world cultural heritage and the protection of Guangxi tradition. It More than 20 traditional ethnic villages in Guangxi were completed the construction and analysis of basic data, which play an important role in the protection of ancient ethnic villages in southwest China. In July 2023, Professor Rosa went to Liuzhou to attend the "China (Guangxi) -Southeast Asia International Forum on Digital Architectural Design " held by Liuzhou City Vocational College. We both exchanged views and discussed the future cooperation.

It has been a good opportunity to share the work of continuing the value of historical civilization conducted in the Guangxi area internationally.

I believe that our cooperation will be more profound and broader in the future.

List of contributors

Prof. Maria Cairoli

Professor in charge at Politecnico di Milano, Italy, with research activities in Building Physics and Applied Acoustics. Deputy Technical Director and Professor in masters for Acoustics (Scuola Master Fratelli Pesenti, Politecnico di Milano, Italy) Acoustics and Theatre Consultant for Performing Art Spaces (including Opera Houses, Concert Halls and Multi-purpose Auditoria with international experience).

Prof. Tommaso Empler

Associate Professor of the Scientific Disciplinary Sector ICAR/17 – Representation. Graduated with honors in 1992 from the Faculty of Architecture of the Sapienza University of Rome. Research Doctorate in Surveying and Representation of Architecture and the Environment obtained in 1998, with a thesis on the Computer Model for Architectural Surveying.
Since 2015 he has been Director of the 3D Modeling & BIM Workshop, which will reach its 10th edition in 2024.
Since 2020 he has been Director of the Master in Heritage, Building Information Modeling (HBIM) at Sapienza University of Rome.
Since 2017 he has been Director of the magazine "Dn. Building Information Modeling, Data & Semantics" since 2017.
They are research topics:
issues related to accessibility and Universal Design;
the forms of representation evolved by means of the electronic computer both in the design and survey fields, with particular development in the Open Source applications sector;
the study of communication systems linked to visual and extra-visual perception;
the development and use of ICT (Information Communication Technologies) linked to the Cultural Heritage sector;
issues related to the HBIM and Digital Twin processes.

Prof. Georgios Kapogiannis

Georgios is an accomplished Associate Professor, certified project manager, consultant, and academic researcher with a strong track record of delivering transformational results and thought leadership in the field of digital construction engineering and project management/leadership. He specializes in designing and implementing digital transformation strategies for Architecture, Engineering, Construction, and Operations (AECO) enterprises, creating and delivering thought leadership content, providing digital construction consultancy services, coordinating digital modeling for construction projects, designing innovative solutions, and fostering a collaborative culture within AECO enterprises and projects. As an Associate Professor at Oryx Universal College in Partnership with Liverpool John Moores University (UK) in Doha, Qatar, Georgios offers valuable insights and practical expertise to students pursuing a degree in digital construction engineering and project management/leadership. He also serves as a Visiting Professor (Research) in Digital Transformation at the Ningbo Institute for Supply Chain Management | MIT Global SCALE in China and a Visiting Professor in Management Information Systems in the College of Business at the University of Northern Iowa in the USA. With a passion for excellence and a commitment to advancing the field of digital construction engineering and project management/leadership, Georgios has received multiple awards and accolades throughout his career. He is dedicated to helping individuals and organizations achieve success through innovative digital solutions and effective project management practices.

Dr. Marco Mari

Sustainability and Policy Advisor, on Sustainable Development issues applied to certification and ESG reporting processes in the context of building, infrastructure and product assets.

With more than twenty years of national and international experience, already member of the Committee of Experts for the G20 Environment 2021 and of the Presidency of the Council of Ministers in support of the Government Commissioner for Earthquake Reconstruction 2016, in the three-year period 2020-2023 he was president of Green Building Council Italy. Co-author of various publications, currently works with important organizations in the private sector and supports, as expert, the Superior Council of Public Works for the new PFTE guideline and the Ministry of the Environment and Energy Security for the revision of the National Plan on Energy and Climate (PNIEC) 2023.

Dr. Athena Moustaka

Dr. Athena Moustaka is an engineer, architect, and early-career researcher in architectural theory and architectural education. She has been Lecturer in Architectural Design at the University of Salford, Manchester, since 2015. She is currently the Programme Director for BSc Architectural Engineering and a member of Salford's Centre for Urban Processes, Resilient Infrastructures & Sustainable Built Environments research group. As an expert in digital Architecture, Athena teaches an array of BIM Design studio modules. Over the 5 years at the university, she has taught across all levels and many of the students that have studied with her are now pursuing their own successful careers in BIM related positions across the UK and Internationally. Athena is a reviewer for top quartile architectural theory publications (Building and Environment, Architectural Research Quarterly, arq, Open House). She has delivered talks to multiple international conferences and chaired relevant sessions in her field. She has also been a Visiting Scholar at San Diego State University, and Northeastern University, as part of Marie-Curie MAPS LED project (RISE researcher, funded under H2020) Her work has been published in journal papers and conference proceedings and she has delivered talks in several universities including Liverpool, Manchester, UCLan and Arizona State University.

Dr. Jolanda Patruno

Jolanda Patruno achieved her MSc degree in Aerophotography and Ancient Topographyat the University of Rome "La Sapienza", (Faculty of Archaeology) on Earth Observation data exploitation for Cultural Heritage and a joint PHD (Italy-France) on the use of full-polarimetric SAR multi-frequency data for the monitoring of desert environments and UNESCO sites in danger. The main line of her PhD research was focused on the use of full-polarimetric SAR multi-frequency data for monitoring desert environments and UNESCO sites in danger, but she gained skills as well in optical medium and high-resolution data processing and GIS. She had been working as Earth Observation engineer for satellite projects focused on EO data exploitation, image quality and performance assessment and Cal/Val activities in Akka Technologies at Telespazio. (Italy). From August 2017, Jolanda has been working for Rhea Group as Earth Observation Data Exploitation and Application Engineer at the European Space Agency (ESRIN, Italy) in the EOP-S andPhiLab Division, providing scientific and engineering support for to a variety of projects and applications as SAR expert.

Prof. Flavio Rosa

MSc in Environmental Engineering and Land Management Faculty of Engineering Sapienza University of Rome. Qualified engineer registered in the register of the province of Rome.
PhD in Energy at the Department of Nuclear Engineering and Energy Conversions (DINCE) Sapienza University of Rome. Adjunct professor in Environmental Building Physics Faculty of Architecture of Rome since 2014. Formerly professor at the 1st level University Master's Degree in BIM, Building Information Modeling, Faculty of Architecture Sapienza Rome, and 1st level Master's Degree in Building Process Management - Project Management.

Research fellow at the CITERA Sapienza University of Rome research center for the “Sun4U” project Empowering and Sharing Tools to Enable Renewable Energy Communities (REC) in Rome. Author of numerous publications in the field of renewable energy and energy requalification in modern and historic buildings.

Responsible for international relations of the SAPIENZA CITERA centre. Expert-advisor to the IURC Australasia program for university cooperation projects on positive energy districts, energy communities and Digital Twin solutions for the built environment.

Visiting professor at the Faculty of Engineering of the Universidad Tecnologica de Panama (UTP) on Digital Twin solutions for the built environment. Coordinator of the International Summer School GIS and BIM for integrated design, Department of Planning, Design, Architectural Technology Sapienza University of Rome from 2019 to today.

Dr. Mario Rossi

Managing director, Design Director and Principal, ambientStudioAn EU licensed, chartered and certified architect, Dr.Mario has a high level of organizational, management anfd leadersip skill. He leads and assesses techinal design with integrity, sustainability, budget, time, client expectations, project design issues in mind. He cultivates a culture of technical excellence, constant clear communication, team coordination and continuous improvement. He has led, advised and provided direction on a vast range of projects, including preparation of master plans, implementation planning, strategy, research, design, maintenance, fit out and operations. Dr Mario holds a PhD in Environmental Sciences from the esteemed Università degli Studi di Firenze – Italy. He is an ASLA International Member, a UGC Urban Green Council Member and a European Commission Evaluation Expert. He has collaborated with several international architecture firms and has liaised with governments for several projects. He is an expert in urban forestry, environmental planning and reforestation including irrigation studies, EIA consultancy and surveys for wetlands, quarries, beaches, soil and rivers restoration using experimental technologies like EBEE drones for surveying. He is a published researcher and an effective lecturer. He has been on several design advisory boards and has been an Expert Scientific Witness for the NYFP Organization at the New York State Supreme Court. He excels in coordination and supervision of various sub consultants - he has been the point of contact for clients, contractors, multiple stakeholders and partners involved in conceptualization, master plans, sustainable design and LEED and ESTIDAMA projects. His vast experience includes state of the art landscape architecture projects, masterplans, high rise structures, green rooftops, green walls, vertical gardens, complexes, residential projects, farms, zoos, urban parks, squares, mixed communities, luxury hotels, resorts, eco villages, streetscape and green retrofitting including green interior design for restaurants and hotels.

Dr. Nurtati Soewarno

I am Dr. Ir. Nurtati Soewarno, M.T, lecturer at the Department of Architecture, Institut Teknologi Nasional Bandung – Indonesia. Bachelor of Architecture (1986) from Institut Teknologi Nasional Bandung, Master of Urban Architecture (2002) from Catholic Parahyangan University Bandung – Indonesia, Course on Conservation & Management of Historic Building (2005) from Lund University Sweden, Course on Urban Land Policy and Implementation (2006) from Institute for Housing and Urban Development Studies in Rotterdam – The Netherlands and Doctor of Architectural (2013) from Catholic Parahyangan University Bandung – Indonesia. My areas of interest are Urban Architecture, Contextual Architecture and Building Conservation. My papers present analyzes and methods for protecting historical architectural heritage in Bandung and other cities. With the adaptive reuse method, cultural heritage buildings can be transformed into other functions while maintaining the authenticity of their architectural style. How the charm of Cultural Heritage Buildings, especially Dutch Colonial heritage buildings, can be used to attract tourists. At present time, by using Building Information Mod.

Dr. Wikan Danar Sunindyo

Wikan Danar Sunindyo is a lecturer and researcher at the Institut Teknologi Bandung, Indonesia. He is also a member of Knowledge and Software Engineering Research Group at the Institut Teknologi Bandung. He studied computer science with emphasis on Automation Systems, Quality Assurance, Data Warehouse and Semantics/Ontology Alignment (Dissertation Title: "Project Observation and Analysis in Heterogeneous Software & Systems Development Environments") and received Dr.techn. (equivalence to Ph.D) from the Vienna University of Technology, Austria. He received an M.Sc. in Computational Logic from the Dresden University of Technology in Germany. He also received Sarjana Teknik degree (equivalence to Bachelor of Science) from the Institut Teknologi Bandung, Indonesia. His research work covers many subjects in knowledge and software engineering areas, including open data, big data, software quality, software process and product improvement, requirements engineering, and ICT for development. He is also a project manager in several national development projects, an organizer of several international events and conferences, a member of some national and international research projects, and a member of Bandung smart city council. He wrote and co-wrote 2 book chapters, 6 journal papers, and more than 40 conference and workshop papers.

Prof. Sisi Tan

A lecturer in the school of Architecture Engineering. BIM technology, engineering cost management and consulting are my research interests. Therefore, I got China Registered cost engineer Certificate and BIM technology qualification Certificate. Published more than 6 unique papers related to BIM technology and prefabricated building construction technology. Hosted a project involving BIM technology and prefabricated building applications, and mainly participated in the three research projects at the district level.

Prof. Claudio Tomazzoli

Claudio Tomazzoli obtained his MSc degree in Electronic Engineering (1997) from the University of Padova, Italy, and his PhD degree in Computer Science (2014) from the University of Verona, Italy. He was an IT professional before going back to studies and is currently a research fellow at the University of Verona. His research interests cover energy saving techniques, machine learning, automatic document processing, and image retrieval.

Dr. Claudia Zylka

Claudia Zylka is a Civil and Environmental Engineer and a PhD candidate in Energy and Environment at the University of Rome "La Sapienza" within the DIAEE - Department of Astronautic, Electrical, and Energy Engineering. She holds with honors a Master's degree in "Project and Construction Management of Building Systems". Claudia has collaborated with architecture and engineering studios working on the energy efficiency of the Italian building stock and completed an internship at A.T.E.R. - Territorial Agency for Residential Construction. Currently she collaborates with the Interdepartmental Center for Research on Territory, Construction, Restoration, and the Environment (C.I.T.E.R.A.). She is the author of the publication in the journal 'Energies' titled "Energy Efficient Solutions: A Multi-Criteria Decision Aid Tool to Achieve the Targets of the European EPDB Directive". She has participated in seminars and conferences addressing topics related to the Digital Twin applied to the built environment.

MODULE I

GIS AND BIM: DIGITAL TRANSFORMATION OF THE CONSTRUCTION INDUSTRY

Digital Renaissance: The University of Nottingham Ningbo China's Journey from Theoretical Blueprint to Augmented Reality

Dr. Georgios Kapogiannis

Co-Coordinator of the Research and Knowledge Exchange Office (RKE) Oryx Universal College in partnerhsip with Liverpool John Moores University - Georgios.K@oryx.edu.qa and Georgios.Kapogiannis@outlook.com

Abstract

The academic world is witnessing a transformative shift, where theoretical paradigms are seamlessly merging with practical implementations. This paper delves into this confluence, specifically focusing on The University of Nottingham Ningbo China (UNNC), a branch of a top 100 global university. As universities globally grapple with the challenges and opportunities of the digital age, UNNC emerges as a beacon, illustrating the journey from conceptual frameworks to tangible, on-ground realities. Through a detailed case study analysis, we explore UNNC's ambitious endeavor to transition into an augmented smart campus. This narrative is enriched by an examination of strategies, collaborations, and technological integrations, particularly the role of Building Information Modeling (BIM), Geographic Information Systems (GIS), and Transdisciplinary Engineering. The outcome presents a holistic vision of a future-ready campus, one that is not just technologically advanced but deeply resonant with the evolving needs of its global community. This paper serves as both an inspiration and a guide, illuminating the path from elaborate theory to impactful practice in the realm of higher education infrastructure.

Keywords: Augmented Smart Campus, Transdisciplinary Engineering, Technological Integrations (BIM, GIS)

1. Introduction to case study – The need

The University of Nottingham, consistently ranked among the top 100 universities globally, has always been at the forefront of academic excellence and innovative pedagogy. Its campus in Ningbo, China, embodies this legacy, serving as a bridge between Eastern and Western educational paradigms. As the digital era ushers in unprecedented possibilities, The University of Nottingham Ningbo China (UNNC) is primed to embrace these opportunities. Recognizing the transformative potential of modern technologies and its role as a beacon of global education, UNNC aspires to transition from its celebrated legacy into a cutting-edge, digitally-augmented hub of learning and innovation. This case study chronicles UNNC's ambitious journey towards becoming an augmented smart campus. We will delve into the confluence of strategies, collaborations, and technological integrations that are guiding this transformation. Through the lens of Building Information Modeling (BIM), Geographic Information Systems (GIS), Transdisciplinary Engineering, and other pivotal elements, we aim to illuminate UNNC's vision for the future - a vision of a campus that is not only technologically advanced but also deeply attuned to the evolving needs of its global community.

Structure

This section delves into the combined field of GIS and BIM. We aim to introduce readers to five main areas:

1. **Data Collection**: Discussing how Survey and GIS techniques gather necessary data.
2. **Information Modeling**: Talking about how 3D models are created and managed, representing both the look and purpose of spaces.
3. **Building Understanding**: Highlighting the importance of teamwork, sharing information, and visualization to

make informed decisions.

4. **Decision Making**: Explaining how the collected data and models help in making strategic choices.

5. **Case Studies**: Sharing real-world examples of GIS-BIM integration. To aid understanding, this chapter includes several instructional videos. They provide an introduction to GIS-BIM, discuss its business implications, and highlight how BIM fosters collaboration.

2. Case Study – Development of the Integrated Smart Campus

The University of Nottingham Ningbo China seeks to transition from its current state to a cutting-edge smart campus. Our team has been entrusted with the design and development of this transformation. This case study outlines our approach, methodologies, and the tools employed to actualize this vision.

Socio-Economic and Technical Assumptions:

- Socio Assumptions: *The campus community, comprising students, faculty, and staff, is tech-savvy and open to adopting new digital solutions.*
- Economic Assumptions: *There's a reasonable budget allocated for the project, prioritizing solutions that offer long-term value and sustainability.*
- Technical Assumptions: *The existing campus infrastructure can support the integration of advanced technological solutions without requiring extensive overhauls.*

Digital Transformation Strategy:

Our strategy hinges on a comprehensive digitalization approach, transitioning from a traditional university campus to an augmented smart campus. Key components of this strategy include:

- Infraworks - *Spatial Management: Utilizing Infraworks to visualize and plan the broader scope of the campus projects.*
- Lumion Rendering: *Employing Lumion for high-quality renderings, ensuring stakeholders have clear visuals of proposed changes.*
- Revit/Sketch Up Modelling: *Building detailed models based on existing 2D CAD drawings to ensure accurate digital representations.*

Augmented Smart Campus Process:

- Assessment: *Evaluate the current infrastructure, technologies, and needs of the university community.*
- Planning: *Utilize tools like Infraworks for spatial management, planning the integration of smart technologies.*
- Design: *Use Revit/Sketch Up for detailed modeling, and Lumion for rendering and visualization.*
- Implementation: *Integrate smart technologies, IoT-based environment management systems, and energy management solutions.*
- Review: *Continuously monitor and adjust to ensure optimal functionality and user satisfaction.*

Digital Platform Development:

A bespoke digital platform was developed to showcase the augmented smart campus. This platform integrates:

- Laser Scanner Modelling: *Scanned point-cloud modelling refers to modelling by scanning the target area or building with a 3D laser scanner. Based on the saved data, manual modelling was performed using Autodesk Recap software.*
- Drone-Photogrammetry Modelling: *Providing accurate aerial models of the campus.*
- IESVE Energy Management: *Simulating and analyzing the campus's energy consumption patterns.*
- IoT-based Indoor Environment Management: *Offering real-time monitoring of indoor environments across the campus.*

Summary: The transformation of The University of Nottingham Ningbo China into an augmented smart campus represents a confluence of innovative tools and a forward-thinking approach. By harnessing a range of technologies and methodologies, we aim to create a campus that is not only technologically advanced but also responsive to the evolving needs of its community.

3. Bridging the Gap: Translating Theoretical Constructs to Real-World Innovations at The University of Nottingham Ningbo China

The University of Nottingham Ningbo China seeks to embrace the wave of digital transformation, transitioning from its current infrastructure to a state-of-the-art smart campus. Our multidisciplinary team has been entrusted with this endeavor, bridging various technological advancements to achieve this vision.

Collaboration:

Seamlessly integrating Geographic Information Systems (GIS) with Building Information Modeling (BIM) is at the forefront of our strategy. Recognizing the "Hierarchy of Human Understanding" as proposed by Tuomi in 2000, we understand that collaboration is paramount. Navigating the balance between adversarial and collaborative stances, our approach is rooted in relationship-building, championing transparency, and mutual regard. Adhering to standards like ISO44001 ensures effective relationship management and partner selection. A successful BIM-GIS collaboration, guided by clear objectives and open communication channels, fosters innovation and ensures efficient project delivery. Collaboration, particularly in the realm of BIM and GIS, yields a multitude of advantages:

1. Problem Solving: Collaborative efforts often lead to more innovative solutions.
2. Reputation: A culture of collaboration enhances organizational reputation.
3. Customer Satisfaction: Collaborative approaches can lead to better project outcomes, thus increasing customer satisfaction.
4. Trust: Collaboration fosters trust among stakeholders.
5. Business Performance: Collaborative projects tend to perform better in terms of timeline adherence and quality.

Successful collaborative-driven projects in the BIM-GIS domain require a well-defined strategy. Here are some guiding principles:

1. Clear Objectives: Ensure that all stakeholders understand the project's goals and their roles in achieving them.
2. Open Communication: Create an environment where team members feel comfortable sharing ideas, concerns, and feedback.
3. Leverage Technology: Use collaboration tools and platforms to streamline communication, document sharing, and project tracking.
4. Conflict Resolution: Establish mechanisms to address and resolve conflicts in their early stages to prevent escalation. The BIM manager plays a pivotal role in fostering a collaborative culture. Their responsibilities encompass:

1. Training: Ensuring that all team members are well-versed in BIM technologies and collaborative practices.
2. Coordination: Facilitating communication between different teams and departments.
3. Quality Control: Monitoring the modeling process to ensure it meets the desired standards.
4. Promoting Collaborative Culture: Actively advocating for open dialogue, mutual respect, and shared decision-making.

BIM and Asset Management:

Our team recognizes the significance of integrating Building Information Modeling (BIM) with Asset Management, especially within collaborative cloud-centric settings. We delve into the architectural intricacies of BIM, emphasizing the importance of visualization in asset comprehension. Our approach is enriched by cloud-based collaborative platforms, ensuring designs that are harmoniously integrated with their surroundings. The seamless integration of BIM for Asset Management in a cloud-based environment necessitates a robust architectural framework. The following components form the backbone of this integration:

1. Data Layer: The foundational layer that houses raw data from various sources.
2. Data Access Layer: Facilitates the retrieval and manipulation of data.
3. Service Layer: Offers services for data processing and business logic implementation.
4. Business Layer: Deals with business logic and rules, ensuring the data aligns with organizational goals.
5. Interface Layer: The user interface where stakeholders interact with the system.

Other essential elements include:

- Maintenance Modules: Covering planned maintenance, reactive maintenance, and work plans.
- Visualization Modules: Providing 2D and 3D ward models, failure representations, and predictive models.
- Service Subsystems: Covering information inquiry, 2D/3D simulation models, predictive models, and interactive gamification.
- Infrastructure Modules: Including a Common Data Environment, Blockchain for data security, real-time sensors, and intelligence.

Building Information Modeling (BIM) as a Business:

Beyond being a technological tool, BIM is viewed as a business paradigm shift. Our strategy seamlessly weaves BIM methodologies with business aspirations, ensuring efficient operations and value amplification. From procurement to information management, our approach encompasses all facets of BIM-centric projects. The integration of BIM into business processes necessitates a reevaluation of several key components:

- Investment: Allocating resources to harness the full potential of BIM.
- Risks: Identifying and mitigating potential challenges and pitfalls.
- Competitive Dynamics: Understanding competitors and carving a niche in the market.
- Unique Selling Point (USP): Determining what makes a BIM-driven project distinct and valuable.
- Innovation: Harnessing BIM to drive innovative solutions and designs.
- International Market: Exploring global opportunities and challenges.

- Resources Management: Efficiently utilizing available resources and ensuring their optimal allocation in BIM projects.
- Iterative Process: Recognizing that BIM-driven projects are iterative, requiring continuous feedback, learning, and adaptation.
- To grasp the profound implications of BIM from a business standpoint, it's essential to delineate certain fundamental concepts:
- What is a Business? At its core, a business encompasses organized efforts and activities to produce and sell goods and services for profit.
- Business Process Management (BPM): BPM is a systematic approach to enhancing an organization's workflow, making it adaptive and sustainable. It is centered around continuous improvement and, unlike projects, is an ongoing operation without a defined end.
- Project vs. Process Management: While project management focuses on accomplishing a specific objective with a clear beginning and end, process management revolves around the governance of continuous operations.
- SWOT Analysis: A strategic tool used to identify and analyze the strengths, weaknesses, opportunities, and threats of a business or a project.

Transdisciplinary Engineering in the Built Environment:

Embracing the principles of Transdisciplinary Engineering (TE), our team cultivates collaboration and holistic solutions. By integrating various learning paradigms and methodologies, such as "The IDea" and the "Canvas Approach," we aim to provide immersive experiences, fostering collaboration and active learning. A unique approach to TE in photoreal environments can substantially augment value for participants. This is achieved by:

- Combining learning approaches such as situated cognition, discovery learning, and constructivism with continuous feedback.
- Engaging learners in experiential learning using the theory of active collaborative learning (ACL).
- Processing and managing the hierarchy of data, information, knowledge, and wisdom (DIKW).
- Promoting collaboration by sharing both digital information and experiences in a collaborative environment.

The ultimate aim is to harmonize people, practices, construction processes, and technology. This fusion culminates in an interactive teaching and learning environment accessible anytime, anywhere.

Digital Transformation (Digital Campus Transformation):

Guided by global case statistics and analytical frameworks like PESTEL, our team ensures a meticulous pre-development analysis. Recognizing that a smart campus is not just about technological integrations but reshaping lived experiences, our approach aims to coalesce the physical realm with the digital, offering immersive experiences for all stakeholders. Hence, the journey of transforming traditional campuses into smart campuses is multidimensional. It requires a confluence of technology, strategy, and stakeholder engagement.

4. Conclusions

The journey of The University of Nottingham Ningbo China towards becoming an augmented smart campus encapsulates the essence of modern academic transformation. This metamorphosis is underpinned by a harmonious blend of innovative tools, forward-thinking strategies, and an engaged community of stakeholders. Such a transformation is reflective of the broader shifts occurring in the construction and design industry, propelled by the Digital Transformation wave. As campuses globally are striving to become more digital, Transdisciplinary Engineering emerges as a pivotal player, melding varied domains of expertise to sculpt comprehensive solutions tailored for the built environment.

Central to this digital renaissance is Building Information Modeling (BIM). When interpreted as a Business, BIM heralds a paradigmatic shift in how architectural initiatives are conceptualized, realized, and sustained. This vision is amplified when BIM converges with Asset Management, emphasizing a holistic lifecycle perspective for infrastructures, ensuring their relevancy and sustainability from genesis to culmination.

However, technology and strategy alone aren't the sole architects of this new dawn. Collaboration is the linchpin. A collaborative ethos in construction and design not only ignites innovation but also ensures a symphonic integration of a project's myriad elements. Through this case study, we've endeavoured to provide a prism through which one can view the future of academic infrastructures – a future that is technologically adept, centered around its users, and finely attuned to the ever-evolving dance of innovation and need.

Acknowledgement:

This case study is featured as a book chapter in 'Smart Buildings and Technologies for Sustainable Cities in China', published by Springer in November 2023. The book is available for purchase at Waterstones. Additionally, the case study can be accessed directly online at https://nile-smart.mysxl.cn/. It has been honored with the Zhejiang Intelligent Competition award and secured the 5th position in the region. Noted that this development took place as part of the module with title Smart Cities and BIM as part of the MSc in Geospatial Engineering and Building Information at the University of Nottingham, Ningbo Campus in China.

Appendix

Further reading in relation to the case study

In the contemporary domain of infrastructure planning and architectural design, a plethora of sophisticated software tools is revolutionizing traditional methodologies. At the forefront of this transformation is Infraworks, a comprehensive infrastructure design software that offers a rich palette of tools to create realistic and contextual models. It provides an intricate bridge to Revit, a renowned 3D modeling software, ensuring that designs are both visually compelling and structurally sound.

The integration doesn't stop at localized models. With platforms like Google Earth, architects and planners can embed their designs into global contexts, enabling them to visualize how new structures fit into existing landscapes. This global-local integration is pivotal when linking spatial data directly to BIM (Building Information Modeling) data, ensuring every element in a design is contextually relevant and optimized for its environment.

Advancements in image analysis, particularly the Object-Based Image Analysis approach, have reshaped how professionals interpret remote sensing data. Instead of traditional pixel-based interpretations, which often lacked context, this method recognizes distinct objects or features. This precision ensures that specific elements, whether they're trees, buildings, or water bodies, are accurately represented in design models.

Visualization plays a crucial role in the design and approval process. Rendering software such as Lumion and Enscape takes raw, skeletal 3D models and transforms them into lifelike visualizations. These renderings, often indistinguishable from real-world photos, allow stakeholders to immerse themselves in the proposed environment, making informed decisions and feedback loops more effective.

Lastly, the analytical prowess of GIS (Geographic Information Systems) software, notably QGIS and ArcGIS, provides the backbone for many crucial decisions. For instance, in regions prone to natural disasters, these tools can map out areas vulnerable to flooding. This information is invaluable, ensuring that designs incorporate preventive and mitigation measures. Additionally, with the rising importance of Lidar data, which offers high-resolution information about the Earth's surface, these GIS tools provide detailed insights, ensuring designs are both functional and harmonious with their surroundings.

Bibliography

YE, Z., KAPOGIANNIS, G., TANG, S., ZHANG, Z., JIMENEZ-BESCOS, C. AND YANG, T. (2023), "Influence of an integrated value-based asset condition assessment in built asset management", Construction Innovation, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/CI-11-2021-0216.

KAPOGIANNIS, G. AND SHERRATT, F. (2018), "Impact of integrated collaborative technologies to form a collaborative culture in construction projects", Built Environment Project and Asset Management, Vol. 8 No.1.

KAPOGIANNIS, G., FERNANDO, T. AND ALKHARD, A.M. (2021), "Impact of proactive behavior antecedents on construction project managers' performance", Construction Innovation, Vol. 21 No. 4, pp. 708-722 https://doi.org/10.1108/CI-02-2020-0029pp. 24-38. https://doi.org/10.1108/BEPAM-07-2017-0043

WALKER, J., TOWEY, D., PIKE, M., KAPOGIANNIS, G., ELAMIN, A. AND WEI, R. (2020), "Developing a pedagogical photoreal virtual environment to teach civil engineering", Interactive Technology and Smart Education, Vol. 17 No. 3, pp. 303-321. https://doi.org/10.1108/ITSE-10-2019-0069

WANIGARATHNA, N., JONES, K., BELL, A. AND KAPOGIANNIS, G. (2019), "Building information modelling to support maintenance management of healthcare-built assets", Facilities, Vol. 37 No. 7/8, pp. 415-434. https://doi.org/10.1108/F-01-2018-0012

Evaluating the Digital Twin framework: key concepts and case studies of Ports in the Lazio Region and the linear infrastructure of the Albanian Capital

Claudia Zylka

Department of Astronautic, Electrical, and Energy Engineering (DIAEE), University of Rome “La Sapienza”, Via Eudossiana 18, Roma 00184, Italia.
claudia.zylka@uniroma1.it

Abstract

This paper endeavors to present an overview of Digital Twin technology’s application in the construction sector, with a particular focus on two case studies. The first case study delves into the structural monitoring of port areas in the Lazio Region, specifically Anzio, Formia, Terracina, and Ventotene. It examines the management of these structures by establishing a system architecture utilizing satellite data from the Copernicus Land Monitoring Service (CLMS) and on-site monitoring. The second case study revolves around the system architecture of a digital twin for linear-road infrastructure in Tirana, Albania’s capital city. The primary goal is to define the application layer for managing safety and security, maintenance, traffic, viability, and overall administration.

Keywords: structural monitoring system, computer vision, linear infrastructure, prediction, real-time control, satellite data, data acquisition

1. Introduction

The concept of the Digital Twin can be traced back to a presentation given by the University of Michigan to the industry in 2002 for the formation of a Product Lifecycle Management (PLM) center. The model is about creating a separate digital version of a physical system. This digital twin includes all the important information about the physical system and stays closely connected to it throughout its entire life. The idea behind the model is that every system is made of two interconnected systems: the physical system, which has always been present, and a new virtual system that collects all the information about the physical system. This leads to a mirroring and twinning of systems [1].

The first definition of the digital twin was coined in 2003 by Michael Grieves and has been further refined and elaborated over time. The first provided is given by Dr. Grieves and dates back to 2017:

“The digital twin is a collection of virtual information constructs that fully describe a physical product, whether it is potential or existing, from the atomic level to the macroscopic level. At its optimal state, any information that could be obtained through inspecting a physical product can be acquired from its digital twin [1].”

It is possible to provide comprehensive and exhaustive definition of the Digital Twin, which is as follows:

“The Digital Twin is a technology that enables the creation of a virtual mirror of the physical world. Equipped with IoT (Internet of Things) sensors and devices, it provides data to describe the physical world virtually. A Digital Twin allows for the aggregation and visualization of data from the IoT, enabling a bi-directional correspondence with an object or space. It possesses computational capabilities that, combined with artificial intelligence (AI), can predict the future and evaluate the future state of the observed entity. Based on the created scenarios, it provides information for decision-making and managing the physical world.”

This is the framework of Digital Twin technology. The Digital Twin, originating from the manufacturing domain, can be developed and applied in the construction industry, providing significant support in all phases of the building process (design, construction, facility management, refurbishment) [2]. It is a complex yet crucial entity in the decision-making process and complements various technologies such as augmented reality (AR) and virtual reality (VR). The concept of the Digital Twin aims to enhance: operational efficiency, resource optimization, resource management, cost savings, productivity and safety [3]. By 2025 up to 89% of all IoT Platforms will contain some form of digital twinning capability [4]. As a result of COVID-19 the 31% [5] of respondents use digital twins to improve employee or customer safety such as the use of remote asset monitoring to reduce the frequescy of in-person monitoring.

The global digital twin marker size was valued at USD 3.1 bilion in 2020 and is projected to reach USD 48.2 billion by 2026 [6]. The application sectors of digital twin are diverse and include: manufacturing and industrial processes, smart cities and infrastructure, healthcare, energy and utilities, transportation and logistics, construction and architecture, environmental monitoring and agriculture.

1.1. Digital Twin for the construction sector

The construction sector can be described as a complex and articulated system, especially in the construction site context, where a multitude of actors and elements interact with each other. The construction industry has experienced a decline in productivity over the past 50 years [7], which contrasts with parallel sectors that have seen significant growth, such as the agricultural sector. The main factor contributing to this situation is the limited digitization of the construction sector, primarily due to resistance to adopting new technologies. Implementing new technologies in such a complex context as construction requires significant effort, often overshadowing the short and long-term benefits that can be obtained.

The low level of digitization is accompanied by other issues that have led to limited productivity and its decline. These include fragmentation within the construction industry, as there is often an artisanal approach to production, with a limited number of workers fulfilling the requirements.

When considering the lifecycle of the construction sector, there is vertical fragmentation [8]. Currently, less than 5% of companies have adopted the Digital Twin technology and the global digital twinning process is still slow [9].

2. Digital Twin study – Ports of Lazio Region and linear infrastructure of Tirana

The first case study explored in this paper concerns the application of the Digital Twin to maritime structures in the Lazio Region. The study gives the background to develop digital twins related to the port areas of Anzio, Formia, Terracina, and Ventotene. Starting from digital processing, a series of action strategies gave the opportunity to build Digital Twins that are based on digital models. Thanks to the continuous synchronization of the digital twin with the real world, it will be possible to act in predictive mode and effectively use economic resources allocated for regular maintenance of port assets. It means that there is a fundamental focus is on the integration of the two technologies, BIM and Digital Twin.

The fields of investigation on which it was decided to build the digital twins primarily refer to cost saving and energy efficiency management, system maintenance, site safety management, and structural maintenance. The focus is made on the last field that is the structural maintenance and the project was developed on three different stages of development: data acquisition, BIM model processing and monitoring system architecture study.

1. **Data acquisition** - In the data acquisition phase, a comprehensive research study on the history, construction, and maintenance of ports over time was conducted. Subsequently, multiple survey campaigns were executed during site visits to gain insights into the built environments and their contextual interactions. Historical research was initially conducted at municipal and regional technical offices to understand the structure of each port. Following this, a visual inspection of each port was performed to gather as much information as possible, particularly focusing on critical areas for later monitoring. Photographic documentation was also acquired to ensure a comprehensive understanding of the area, which would be integrated into future models. All information gathered during this phase was compiled into a repository for use in the subsequent stages.
2. **BIM Model processing** - In the second phase, the respective digital models of each port area were reconstructed. Initially, connections were established for each photograph within the "SURVEYS" folder, and these photographs were then integrated into parametric objects known as "cameras" using specific path parameters within the digital model of each port. Autodesk Revit version 2022 was utilized for this work.
3. **Monitoring system architecture study** - In the third phase, the architecture of the monitoring system for each port was defined. Two distinct structural monitoring systems were considered. One relied on satellite data from the Copernicus Land Monitoring Service (C.L.M.S.), while the other involved on-site monitoring.

2.1. Structural monitoring system for the ports of Anzio, Formia and Terracina

The monitoring methodology using satellite data is specific to ports with particular structural criticalities. The data processing process takes as input the processed measurements, consisting of two components of deformation along the vertical and horizontal directions. The Calibrated dataset contains a much larger number of measurement points within a single area, with higher measurement accuracy and precision, thanks to the integration of measurements with GNSS data. The methodology allows for hundreds of additional points compared to the previous method, but at the same time, the exponential increase in the number of surveyed points tends to provide datasets with millions of rows that are almost impossible to handle quickly and efficiently (Fig.1). The historical data for the selected monitoring points span from January 5, 2016, to December 16, 2021.

After zoning the port area, the monitoring points were selected. The criteria for choosing the points were: the point, if possible, should be selected in a barycentric position within the monitoring zone; points too close to the sea should be avoided; points with clearly anomalous and variable historical trends should be avoided. It was possible to assess the vertical and horizontal movement of these points over time. This approach allowed for the activation of a system alert when a point exceeded a predefined threshold value in terms of positional changes.

Fig. 1. Structural monitoring system relied on satellite data from the Copernicus Land Monitoring Service (C.L.M.S.)

2.2. Structural monitoring system for the port of Ventotene

Regarding the structural monitoring of the critical area of the quay at the Ventotene port, identified at the mooring area of the hydrofoils between the height of the prefabricated beams and their respective structural casings and verified during the conducted surveys, a sensor instrumentation was installed on-site to transmit real-time data, unlike the approach adopted for the ports of Anzio, Formia, and Terracina.

The survey conducted presented an opportunity for the work team to examine the specific intervention area with the full cooperation of municipal technicians, to whom inquiries were directed. This facilitated the determination of the correct and optimal location for installing video cameras to monitor the quay's structure using AI (Artificial Intelligence) technology, commonly referred to as Computer Vision or Artificial Vision (Fig.2). By analyzing the information derived from digital images captured by the cameras, it becomes feasible to monitor any type of structural movement of the quay. This is achieved by overlaying images captured at different time intervals and activating alerts when deviations above a predetermined threshold are detected.

Fig. 2. Original image and Result of Visual Monitoring Points Extraction (red boundary lines of the quay).

From a structural point of view, a repeater is installed near the lattice structure located on the roof of the Ventotene town hall building to ensure effective connectivity in the port, thereby creating a radio bridge. Above the lattice of the port's video surveillance cameras, a radio bridge antenna is positioned. Connectivity is transported via a waterproof cable to the rack - a mechanical support structure (cabinet) on which the hardware components are mounted - where a network switch is placed. The network switch enables the signal to reach the cameras. Specifically, three cameras are nested on the lattice of the port quay, where security cameras are already present. Due to the absence of electrical power on the monitoring quay (except for the power supplies provided for hydrofoils), a power socket must be arranged for the current at approximately 50 meters from the panel containing the network switch, placed close to the lightning protection wall (Fig.3).

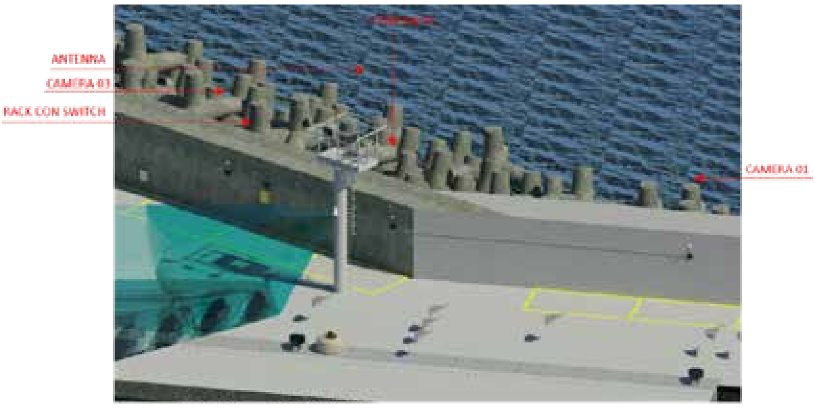


Fig. 3. View from the installed on-site plant structure model in isometric perspective.

A complementary and completion monitoring approach is implemented through the installation of so-called single-axis digital electric crackmeters, which are precisely linear elements made of stainless steel equipped with potentiometric displacement sensors capable of detecting small position changes between the two points placed on either side of a joint, with a measurement range of up to 250 mm. In the case of the Ventotene port, this system is positioned near the widening of the first section of the quay towards the sea, oriented towards the lateral docking of the hydrofoils rather than on the surface. The control unit is positioned inside the flower bed. Data is remotely read using the NB-IoT transmission module, a system powered by a low-consumption, long-lasting battery. This data is transmitted to a server through the NB-IoT connection (dedicated internal SIM card). The server receives and archives the data, processing it in graphical or tabular form and making it available in real-time in a restricted area. This software platform manages the system directly from the web. Remote devices communicate with the server through a GPRS data connection. System access is protected by a user ID and password and can be accessed with a standard internet browser. Daily data backups are performed.

3. Application of Digital Twin models to the built environment – the study case of Tirana

The following study gives the basis for the application of the Digital Twin architecture. Thanks to its integration with Artificial Intelligence, it gives life to an increasingly intelligent system, to a linear infrastructure that specifically involves the road network and urban mobility [10].

In this case, the Digital Twin is extended to the chaotic and fragmented linear infrastructure of the city of Tirana, controlled by a basic IoT management platform characterized by the presence of a sensor system and video surveillance cameras.

3.1. Historical context and challenges of the Albanian capital

Tirana's urban development, essential for understanding the Digital Twin Model research, reflects a dynamic evolution. It started as a small city and grew into a metropolis, with ongoing expansion [11]. The transition from a totalitarian to a market-based regime in the 1990s marked significant urban development in Albanian cities, with newfound freedom in construction [12].

Population migration from rural areas to cities, seeking opportunities, drove Albanian urban growth. Tirana, the capital, saw rapid population increase: from 35,000 in 1937 to 601,000 in 2007, projected to reach one million by 2030, hosting 31.84% of Albania's population [11]. This growth fueled a construction boom and suburban expansion. Old neighborhoods filled up, and new suburbs emerged, reshaping Tirana from a radial to a linear city, with boundaries expanding indefinitely, incorporating green areas. Tirana's urban form shifted from polycentric to monocentric and back to polycentric in recent decades, blending orthogonal and radial patterns. This led to significant urban stratification, shaping the city's identity. Historic heritage faced threats as residential buildings encroached on open spaces, erasing historic traces. The urban landscape transformed chaotically, lacking guidelines, creating a fragmented, low-quality residential fabric, and undermining public spaces [12].

3.2. Urban mobility in Tirana and current state of the road system

Tirana faces significant urban challenges, primarily related to its road infrastructure and mobility issues. The city's urban pattern is disorganized, leading to a congested road network, especially within the two main ring roads encircling the center. This congestion is a constant problem throughout the day. Additionally, Tirana has a concerning issue with road accidents, including fatal ones, which have been on the rise in 2023. Factors contributing to these accidents include irresponsible driving, alcohol and drug impairment, and high speeds, affecting not only motor vehicles but also pedestrians and cyclists.

Efficient road maintenance is another challenge for Tirana, with limited financial resources often resulting in inadequate upkeep. Finding cost-effective solutions for maintaining the road infrastructure is crucial, given its significance for the city's socioeconomic development. Moreover, several ongoing mobility infrastructure projects in Tirana remain incomplete, adding to the city's transportation challenges.

Currently, Tirana's linear road infrastructure relies on a basic IoT management platform, incorporating sensors and surveillance cameras with human oversight to detect and manage traffic. Traffic police are also consistently present in the city center and congested areas. Additionally, there is a maintenance plan in place for street lighting, traffic lights, and surveillance cameras.

3.3. Applications of the Digital Twin to resolve road infrastructure challenges and applicative methodologies

The development of digital systems presents an opportunity to transform urban environments into smart and interconnected cities, offering efficiency and innovation in areas like transportation, healthcare, well-being, and energy efficiency. This paper focuses on road intersections and aims to enhance safety, predict accidents, optimize mobility services for both vehicles and pedestrians, and efficiently manage road convergence points through real-time monitoring and intelligent control. The proposed architecture for the Digital Twin system for linear infrastructure consists of four layers:

Physical Layer: This layer encompasses various components of the road infrastructure, including physical elements like roads, streetlights, signage, and traffic controllers, as well as entities involved in traffic such as vehicles, drivers, pedestrians, and cyclists. Actions like departures, arrivals, and mobility, along with the surrounding environment, like weather conditions, are also considered.

Data Layer: The Data Layer combines dynamic and static data, including information about entities involved in traffic, their actions, the intelligent infrastructure, and the surrounding environment. It acts as a repository for all relevant data.

Model Layer: In this layer, the actual Digital Twin model of the infrastructure is created. This model constantly exchanges information with the physical model and the Data-Driven model.

Application Layer: The Application Layer utilizes advanced techniques such as Machine Learning (ML), Deep Learning (DL), and Artificial Intelligence (AI) to develop a predictive and control system. This layer is responsible for making real-time decisions and optimizations (Fig.4).

By implementing this architecture, the challenges of road infrastructure can be effectively addressed, resulting in improved safety, efficiency, and optimized mobility within the city. The development process of a Digital Twin framework begins with collecting historical data, which is often imperfect and needs preprocessing to ensure data quality. Real-time data from IoT devices, sensors, cameras, and other sources are also integrated. For the case of Tirana, historical data includes information about surveillance camera locations, road issue statistics, data from intelligent traffic lights, parking area mapping, street lighting maintenance plans, data from existing sensor systems, maintenance scheduling data, ongoing infrastructure projects, and traffic models. This data collection approach emphasizes the importance of Big Data in building the Digital Twin. The next step involves selecting suitable Machine Learning algorithms for the dataset and then training and testing the Data-Driven Model. Simultaneously, a Physical Model of the road infrastructure is developed. In the final phase, the Digital Twin Model is created, incorporating AI, ML, DL, and other technologies to establish a predictive and control system that can simulate various scenarios, aiding in maintenance decisions, including optimal timing, location, and priorities. This approach demonstrates how digital technologies, such as ML, DL, AI, IoT, Big Data, and sensorization, can be leveraged to address civil engineering challenges and enhance urban infrastructure management.

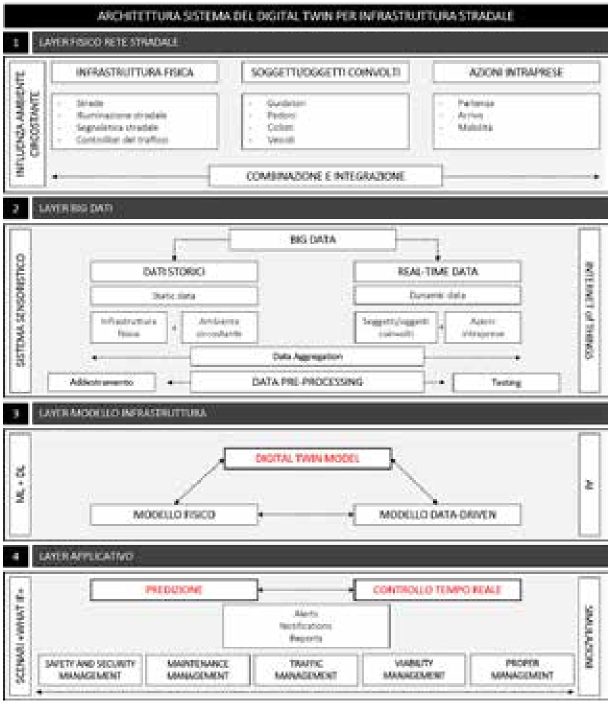


Fig. 4. System architecture of the DT for road infrastructure.

4. Conclusions

The implementation of the structural monitoring system for the port areas of Anzio, Formia, Terracina, and Ventotene through Digital Twin technology aims to enable the detection of potential structural issues by monitoring port docks and access channels. Consequently, it seeks to achieve significant cost savings through the optimization of port area performance and intelligent planning and management of routine maintenance interventions.

The Digital Twin system for Tirana's linear infrastructure aims to address issues of congestion, road accidents, and road maintenance. This involves the creation of a comprehensive Digital Twin project for Tirana's linear infrastructure, resulting in a sophisticated predictive and control system for real-time urban road management. Key areas of focus include Safety Management, Maintenance Management, Traffic and Viability Management, and handling anomalies and unforeseen events. Data-driven simulations will play a pivotal role, enabling testing and optimization of processes before physical implementation. This approach reduces installation time and enhances product quality. The system relies on sensors capable of capturing data, with a continuous influx of data improving Machine Learning algorithms' understanding of infrastructure history and conditions. This data-driven learning process is crucial for constantly refining maintenance methodologies. Additionally, the video surveillance system contributes valuable information through Computer Vision by detecting chromatic variations in images, signaling deteriorating performance of streetlights. Leveraging open-source satellite data supplements the existing sensor network, enhancing system modularity and replicability. This approach promises to make a positive impact on Tirana's urban infrastructure management.

Bibliography

1M. Grieves "Origins of the Digital Twin Concept", August 2016, DOI: 10.13140/RG.2.2.26367.61609.

H. Omrany, K. M. Al-Obaidi, A. Husain, A. Ghaffarianhoseini "Digital Twins in the Construction Industry: A Comprehensive Review of Current Implementations, Enabling Technologies, and Future Directions", Sustainability 2023, 15(14), 10908; https://doi.org/10.3390/su151410908.

S. Evans, Beyond buzzwords: "The true meaning and value of 'digital twins'", 2019. Digital twins for the built environment-SNC Lavalin group.

"Digital Twins Market, 2020: Up to 89% of all IoT Platforms will Contain Some Form of Digital Twinning Capability by 2025" - ResearchAndMarkets.com.

"Gartner Survey Reveals 47% of Organizations Will Increase Investments in IoT Despite the Impact of COVID-19".

"Digital Twin Market by Application (Predictive Maintenance, Business Optimization, Performance Monitoring, Inventory Management), Industry (Automotive & Transportation, Healthcare, Energy & Utilities), Enterprise and Geography – Global Forecast to 2028", MarketsandMarkets.

"The construction industry's productivity problem", Aug 17th 2017, Economist.com.

Md. A. Hossain, A. Zhumabekova, S. C. Paul, J. R. Kim "A Review of 3D Printing in Construction and its Impact on the Labor Market", Sustainability 2020, 12(20), 8492; https://doi.org/10.3390/su12208492.

D. M. Botin-Sanabria, A. S. Mihaita, R. E. Peimbert-Garcia, M. A. Ramirez-Moreno, R. A. Ramirez-Mendoza, J. D. J. Lozoya-Santos "Digital Twin Technology Challenges and Applications: A Comprehensive Review" Remote Sens. 2022, 14(6), 1335; https://doi.org/10.3390/rs14061335.

S. Agostinelli, G. Guidi, F. Cumo, C. Tomazzoli "The Potential of Digital Twin Model Integrated With Artificial Intelligence Systems".

F. Naselli, K. Tufina "Beyond the Official City Planning. Tirana Next Pilot for Healthier and Safer Urban Open Spaces in the Post-2020".

E. Dobjani "La qualità dello spazio residenziale a Tirana".

M. Colleoni "Mobilità e rigenerazione urbana".

G. Qirjako, G. Burazeri, B. Hysa, E. Roshi "Factors Associated with Fatal Traffic Accidents in Tirana, Albania: Cross-sectional Study".

K. Chen, M.E. Torbaghan, M. Chu, A. Garcia, L. Zhang "Identifying the most suitable machine learning approach for a road digital twin; a systematic literature review".

V.M.G. Martinez, M.R.N. Ribeiro "Intelligent Road Intersections: A Case for Digital Twins".

17. S. Agostinelli "Cognitive Digital Twin for Building Management systems: a case study in Rome".

National and International Energy and Environmental rating system protocols: the answer to the requirements for reporting and certification of the sustainability of built environment

Marco Mari

Sustainability Adviros, Former President GBC Italia

1. The Building System: A cultural revolution even before a technical one

An ever-widening awareness that resilience, sustainability and healthiness are central to our built environment leads us to reflect on how to find the right balance between the three main components of environment, society and economy. This tension is imposing a decisive acceleration on issues relating to the objectives of decarbonization, circular economy, healthiness and a more marked attention, among all the production chains, to those of construction and real estate.

Paul Hawken declared: “The construction sector is not only the largest industrial sector in economic terms, but also in terms of resource use.” In fact, focusing on emerging environmental issues, the situation is particularly clear, considering that buildings in Italy are responsible for approximately 40% of overall primary energy consumption, 50% of extracted raw materials, 21% of water consumption, emissions from construction account for over 36% of climate-altering emissions, and that the waste attributable to the entire construction chain in Europe is in the order of 50% by weight of all waste produced[1].

2. The real estate assets and the green and blue infrastructure refurbishments, carried out according to international definitions

“Pieces of green do not make a sustainable building.” It is with this incipit that U.S. Green Building Council began its international conferences over twenty years ago, in order to guarantee a correct approach to real estate assets and green and blue infrastructures.

For the real estate assets, the aforementioned Building System was identified with the definition of “Green Building” (internationally validated by the regulatory body ASHRAE[2]), assets that in their life cycle are capable, at the same time, of:

- Minimize the consumption of natural resources through more efficient use of non-renewable natural resources, land, water and building materials, including the use of renewable energy resources to achieve net zero energy consumption;
- Minimize emissions that negatively impact our indoor environment and our planet’s atmosphere, particularly those related to indoor air quality (IAQ), greenhouse gases, global warming, particulate matter or acid rain ;
- Minimize the discharge of solid waste and liquid effluents, including demolition and occupant waste, sewer and stormwater, and associated infrastructure necessary to enable removal;
- Minimize negative impacts on surrounding site ecosystems.
- Maximize the quality of the indoor environment, including air quality, thermal regime, lighting, acoustics/noise and visual aspects to provide comfortable human physiological and psychological perceptions.

Definition to which GBC Italia added a further aspect in 2015:

---

[1] GBC Italia, ANCE

[2] Green Guide:The Design, Construction, and Operation of Sustainable Buildings, 2006, pg. 4. (www.ashrae.org)

- Maximizing the cultural and testimonial value of the properties, this additional focus also allows us to take into account the aspects of a Mediterranean matrix, in order to contemplate the correct protection of the buildings also from a historical-testimonial profile, in order to foresee what we could call it a “right construction”, i.e. the ability to design and create assets capable of lasting a long time (avoiding actions based on a purely speculative and consumerist approach) while safeguarding what is most important.

The ASHRAE definition together with what has been added by GBC Italia allows, also and above all for redevelopment interventions of existing used and historical-testimonial assets, consistent with a new paradigm capable of combining the aspects of “Heritage & Sustainability” (culture and sustainability) with in order to transfer to future generations the same environmental and cultural values that we can enjoy today.

A building that pursues redevelopment in coherence with the aspects of sustainable development according to this paradigm allows the entire life cycle to be approached, whatever its destination or cultural origin, from a redevelopment perspective, considering both the reduction of primary energy needs and impacts on further environmental and social aspects, but also to create resilient assets and therefore capable of dealing with climate crises and recent meteorological and seismic events.

For the green and blue infrastructure, according to ISTAT’s 2021 “Urban Environment” survey, in Italy there are 32.5 square meters of urban greenery per inhabitant. The European average is 42.3 square meters, while the best positioned country is Denmark, with 100 square meters per inhabitant. Considering that urban greenery contributes significantly to mitigating the effects of climate change and improving people’s psychophysical well-being, the indication is clear: we cannot focus attention only on economic capital (from buildings, to roads, to bridges, to infrastructures in general, etc.), but we also need to focus simultaneously on natural capital (from forests to glaciers, from parks, to squares, to gardens, etc.).

To this end, the Definition of green and blue infrastructure [Source: Green Infrastructure (GI) - Enhancing Europe’s Natural Capital - COM(2013) 249 final] will be useful, the European Union defines Green Infrastructure as:

“a strategically planned network of natural and semi-natural areas together with other environmental elements, designed and managed to provide a wide range of ecosystem services such as water purification, improved air quality, space for leisure, mitigation and adaptation to climate change, protection and increase of biodiversity in rural and urban areas as well as in natural territories”.

In any case, the assets interact with each other and a correct approach to complexity suggests that they must be considered in an integrated way, in which all the more reason only one vector cannot be addressed at a time, such as the energy vector separated from the other and from the context.

3. Refurbishment, regeneration and redevelopment of green and blue infrastructures and buildings: constraints and opportunities with respect to the main national and international trends

The signals coming from the market highlight that development is only possible if it is sustainable. In fact, studies relating to the growth trends of the sustainable construction sector certified in compliance with the main energy-environmental protocols (rating system) speak of unprecedented increases.

As regards constraints in the field of **public assets**, regeneration projects with the use of energy-environmental protocols are increasing, driven mainly by the EU Taxonomy Regulations and already foreseen as a reporting system in conjunction with the defined Green Public Procurement processes since 2017. in the Minimum Environmental Criteria (CAM) for Construction issued by the Ministry of the Environment and Energy Safety. To date, the August 2022 revision of the Building CAMs has also extended the application to buildings with historical-testimonial value, as well as in the recent Technical Economic Feasibility (PFTE) project, as required by the new Procurement Code (Legislative Decree 36/2023), with particular reference to Art. Article 57 (Social clauses of the tender notice and notices and energy and environmental sustainability criteria) or in Annex I.7 and in Annex I.7 section II.

There are many leadership opportunities for public and private assets.

Internationally, over 15 billion square meters of buildings (worth over four trillion dollars); 70% increase in the global green building market by 2025.

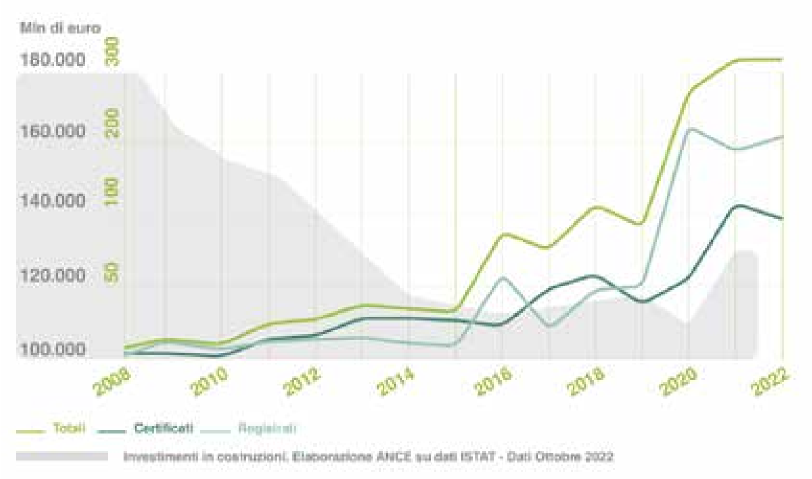


Fig. 1. At a national level - the recent GBC Italia 2023 Impact Report[3] mostra una posizione di tutto rispetto del nostro Paese per quanto attiene all'utilizzo dei protocolli energetico- ambientali della famiglia LEED-GBC. Di fatto, l'Italia è seconda dopo la Spagna e prima della Germania, disponendo di un elevato numero di edifici in corso di certificazione (formalmente registrati) e già certificati sui protocolli della famiglia LEED-GBC (oltre 19.8 milioni di mq per oltre 1430 edifici.

Numero di edifici e relative superfici LEED e GBC	
Numero progetti totali:	1460
Numero progetti registrati:	890
Numero progetti certificati:	570
Area superficie lorda totale [mq]:	19.851.417,45
Area superficie lorda certificata [mq]:	9.191.525,18

Fig.2. Andamento della numero edifici registrati e certificati LEED + GBC negli anni a confronto con l'andamento degli investimenti nelle costruzioni (elaborazione GBC Italia: Impact Report 2023)

---

[3] Impact Report 2023 "L'impatto dell'edilizia sostenibile certificata in Italia" a cura di GBC Italia (https://bit.ly/42Dhupj).

4. LEED® energy-environmental protocols

LEED®, acronym for Leadership in Energy and Environmental Design, is a voluntary system, born thanks to U.S. Green Building Council[4], and consensus-based, for the design, construction and management of sustainable buildings and high-performance territorial areas and which is increasingly developing internationally; It can be used on any type of building on a university campus. On the merits, it allows us to provide a guideline from the technical-economic feasibility project, to the design, construction, up to the sustainable management of the same property, therefore on the entire process.

The reporting process takes place through LEED Online[5] platform dedicated to managing the LEED reporting and certification process. Through LEED Online, design teams can register, manage project details, complete documentation required for LEED® credits and prerequisites, upload supporting files, submit documentation for review, receive reviewer comments, and ultimately obtain approval. certification.

The certification is issued by the international body by a single body called Green Business Certification Inc (GBCI)[6] is an independent third-party organization committed to ensuring the correct implementation and compliance of the processes and performance of real estate assets.

5. GBC energy-environmental protocols

The GBC protocols were developed thanks to the work of the committees of the Green Building Concil Italia association, applying an approach based on subsidiarity criteria, through inclusive processes and therefore representing all the interested parties in the building supply chain and were created, thanks to a agreement with U.S. GBC, from the international LEED® rating systems, the most widespread and used in the world. Specifically, the GBC protocols refer to the Italian and European construction and regulatory reality and apply to different types of buildings (historic, residential, condominiums) but also to portions of territory (neighborhoods) and concern all development phases: from design to implementation and retraining to improve management.

The protocols developed specifically for the Italian market and applicable to university housing are:

GBC Home®[7], with specific reference to new or redeveloped university housing buildings of up to 10 floors, which may also include a small part intended for non-residential functions.

GBC Condomini®[8], with specific reference to existing residential buildings, including university housing in cases of partial improvement of the energy-environmental characteristics of the building, also in order to combine the durability aspects of the building (structural, fire prevention, etc.).

GBC Historic Building®[9], in relation to historic buildings, GBC Italia has also made available to the market and the Public Administration the first protocol worldwide which in a holistic way allows the energy and environmental quality aspects of the building to be correlated with its historical value: GBC Historic Building®. This protocol is applicable to university housing, as well as to any further use function in the case of redevelopment of a building with historical-testimonial value.

GBC Quartieri®[10], in relation to the neighborhoods for which GBC Italia has made the GBC Quartieri® protocol available to the market and the Public Administration which is holistically applicable for built-up area projects (from two buildings to entire neighborhoods or small towns). The certification encourages best practices oriented towards the analysis of the territory, the choice of areas in relation to environmental preservation, promoting the connection to public transport, the relationships of areas with pre-existing structures, the creation and development of social services

---

[4] https://www.usgbc.org/

[5] https://www.leedonline.com/

[6] https://www.gbci.org/

[7] https://gbcitalia.org/web/guest/home1

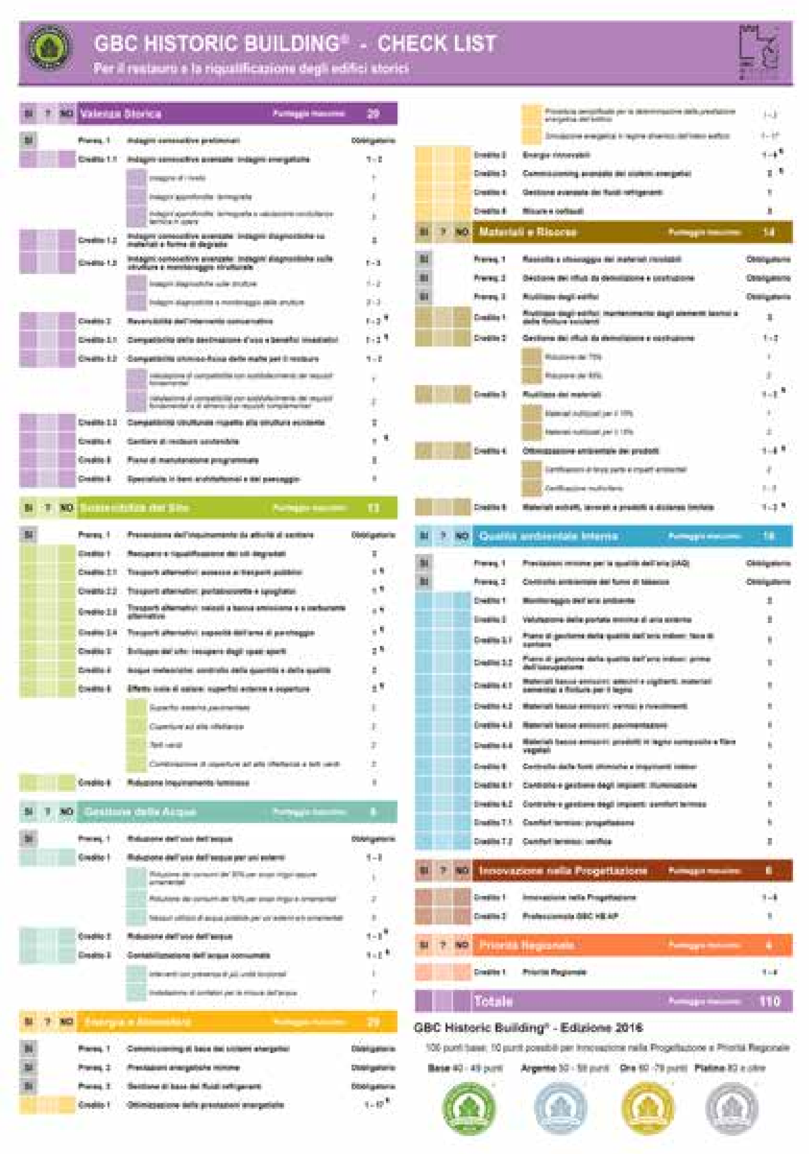
[8] https://www.gbcitalia.org/web/guest/condomini

[9] https://www.gbcitalia.org/web/guest/historic-building

[10] https://www.gbcitalia.org/quartieri

and functions.

For further additional information, see the document drawn up by GBC Italia entitled “GBC Italia Handbook for the application of environmental energy protocols and CAMs to the building process in the public sector” which represents a valid recently published guide[11].



GBC HISTORIC BUILDING® - CHECK LIST
Per il restauro e la riqualificazione degli edifici storici

Fig.3. The figure shows the GBC Historic Building® protocol scorecard as an example.

The **accountability process** takes place through a platform dedicated to managing the GBC reporting and certification process. Specifically, GBC Italia provides a specific online repository for each project in order to manage the reporting details both during the design and construction phases of the work and complete the documentation required for the credits and prerequisites of the GBC protocols.

---

[11] Il “Prontuario GBC Italia per applicazione dei protocolli energetico ambientali e dei CAM al processo edilizio in ambito pubblico” in REV 0 del 09/06/2022 è scaricabile al seguente link: https://gbcitalia.org/wp-content/uploads/2022/11/220629_Linee-guida-PA_DEF_compressed.pdf

The certification is issued by a single national body called Green Business Council Italia (GBC Italia)[12], which in addition to defining the GBC protocols, operates as an independent third-party organization committed to ensuring the correct implementation and compliance of the processes and performance of real estate assets. The certification process through checks by Accredited Verification Bodies (OVA), accredited by GBC Italia on the basis of pre-established prerequisites, which also include Accredia accreditation for specific schemes, structure requirements and specific process competence requirements. The OVA coordinate teams of Qualified Inspectors (IQ), who are specifically qualified by GBC Italia. The certification process begins with the contract of candidacy of a building for certification and commitment to audit services, signed by the client or its legitimate representative with GBC Italia, phase called "registration" and when requested by the client continues with the actual certification contract. Once the certification contract has been activated, GBC Italia assigns the verification activities to an OVA, which appoints its own team to review the inspection activities by choosing the Inspectors among those who have passed a rigorous qualification process carried out by GBC Italia.

6. The LEED-GBC certification processes make it possible to report and valorise the reduction of the impacts generated, also and above all with regards to buildings used for university housing

The refurbishment of an existing building used as university housing, similarly to what was expressed in the recent Impact Report previously mentioned, if carried out in compliance with an energy-environmental protocol allows consumption to be contained and well-being and healthiness to be increased, acting directly on:

- energy consumption, thanks to efficiency solutions
- consumption from renewable energy, thanks to self-production solutions
    - Indoor water savings, thanks to recovery solutions and the adoption of water efficiency solutions
    - Outdoor water savings, thanks to recovery solutions and the adoption of external water efficiency solutions
    - CO2 emissions related to mobility avoided thanks to the location of the property and the proximity to public transport and the incentive of soft mobility solutions
- Less generation of general waste on site
    - Less generation of construction and demolition debris on site
    - Increased use of recycled building material

An idea of the overall quantity of greater positive externalities, compared to the entire stock of certified buildings at the end of 2022, is visible in the following figure taken from the GBC Italia Impact report. The impacts previously stated are expressed as a physical quantity to which an economic equivalent is associated which represents the monetary value of the externality. The quantification of the monetary value of CO2 (Social Cost of Carbon) is deduced from the scientific literature in the sector[13].

---

[12] https://www.gbcitalia.org/

[13] Data processing "the house Ambrosetti", GBC Italia, USGBC, GBCI, ARC SKORU data front, on methodologies taken from scientific literature: Ricke, K., Drouet, L., Caldeira, K., & Tavoni, M. (2018) . Country-level social cost of carbon. Nature Climate Change, 8(10), 895-900

Fig.4. The figure shows the summary of the annual impacts enabled by the LEED-GBC protocols. Source: The European House – Ambrosetti elaboration on GBC data, ARC SKORU, ENEA, FederCostruzioni, Terna and European Commission, 2023.

For further information, please refer to the GBC Italia 2023 Impact report, which can be freely downloaded at the following link: https://bit.ly/42Dhupj.

MODULE II

GIS-BIM THEORY AND PRACTICE

Leveraging Heritage Building Information Modeling (HBIM) for Conservation and Promotion of Traditional Architecture in Jordan

Athena Moustaka

School of Science, Engineering and the Environment, University of Salford, M54WT, UK

a.moustaka@salford.ac.uk

Abstract

This paper explores the application of Heritage Building Information Modeling (HBIM) in the context of traditional architecture conservation in Jordan. It discusses the advantages of HBIM, through the lens of the project "IT Conservation of Traditional Heritage in Jordan", funded by the Royal Academy of Engineering. It begins with an overview of the project, followed by the role of stakeholders, insights from research and fieldwork and reflection of the project goals achieved. The paper emphasizes the role of stakeholders in managing expectations for implementing BIM in Heritage, as well reviewing the challenges of data collection. The outcomes of the project highlight the significance of technology and innovation in safeguarding cultural heritage and fostering cross-collaboration among diverse stakeholders.

Keywords: Heritage Building Information Modeling (HBIM), Stakeholder engagement, Technology in heritage conservation, Digital documentation, Digital heritage repositories

1. Introduction

The cultural heritage of Jordan is a rich amalgamation of historical, architectural, and archaeological objects and sights spanning over 2500 years. The preservation of this heritage is not only a matter of local pride but also a global responsibility, with six sites already having achieved UNESCO World Heritage Status [1] (including Petra, Wadi-Rum and As-Salt, and several others currently shortlisted). However, the preservation of heritage is not limited to grand archaeological sites but extends to traditional architecture that characterizes Jordan's urban landscape. To ensure the safeguarding and promotion of Jordan's rich cultural legacy, the Herit-IT Jordan Project was initiated with a generous grant from the British Royal Academy of Engineering with a particular focus on the potential of Heritage BIM to be used by professionals contributing to the conservation and promotion of traditional architecture.

In recent years, there is growing interest in Jordan to preserve the heritage of the country in an effort to promote tourism in the country. This is evidenced by the coexistence of Tourism and antiquities under the portfolio of the same ministry [2]. In this paper, we delve into the role of Heritage Building Information Modeling (HBIM) and how it can be used to bridge innovation and history in preserving our heritage. It aims to shed light on the pivotal role of Heritage Building Information Modeling (HBIM) in traditional architecture conservation and promotion. Following an overview of the project, share the accomplishments of the Herit-IT Jordan Project in relationship to HBIM, and emphasize the importance of cross-collaboration among stakeholders in preserving our cultural heritage.

2. The Role of Stakeholders in Heritage Conservation

Part of the difficulty in working with Heritage sites of architectural significance, is that it involves multiple diverse stakeholders, including historians, archaeologists, architects, engineers, government bodies, and local communities. In this particular case, we identified all parties potentially involved as: Ministry Of Tourism And Antiquities, Local Municipalities, Banks/Capital Investment, Local Planning Office, National Committee, Local Communities, Local Practitioners, Local Tourism Municipality, National Tourism Board, Agencies/NGO's Local Entrepreneurs. Effective collaboration among these stakeholders is essential for successful heritage preservation. It was important from the early stages of the project to incorporate stakeholders in the project, to ensure a successful outcome.

To understand the level of involvement of our stakeholders in the project, we referred to Mendelow's Stakeholder Matrix. This is a widely recognized framework that helps organizations understand and categorize their stakeholders based on their level of interest and influence. It distinguishes them into four main categories: Low Interest/Low Influence, Low Interest/High Influence, High Interest/Low Influence, and High Interest/High Influence [3].

2.1 **Low Interest/Low Influence (Minimal Effort):** These stakeholders have minimal interest in the organization's activities, and their influence is also low. They are often considered less critical to the organization's success, and communication efforts with them may be minimal.

2.2 **Low Interest/High Influence (Keep Informed):** Stakeholders falling into this category may not have a strong personal interest in the organization's activities, but they hold high levels of influence due to their position or connections. It is important to keep them informed to prevent them from becoming disinterested or even adversarial.

2.3 **High Interest/Low Influence (Keep Satisfied):** These stakeholders have a high level of interest in the organization's activities but relatively low influence. They may be customers or clients who rely on the organization's products or services. While they may not have the power to make decisions, their satisfaction is crucial for the organization's success.

2.4 **High Interest/High Influence (Manage Closely):** Stakeholders in this category possess both a high level of interest and significant influence. They are typically key players who can impact the organization's decisions and outcomes. Managing these stakeholders closely is vital to ensure a positive and mutually beneficial relationship.

Mendelow's Stakeholder Matrix offers a structured approach to assess, prioritize, and manage stakeholder relationships. By categorizing stakeholders into these four groups, organizations can tailor their communication and engagement strategies to meet the specific needs and expectations of each group. For the purposes of this project, we located on the matrix all identified stakeholders to assist with decision-making, risk management, and the development of appropriate engagement plans.

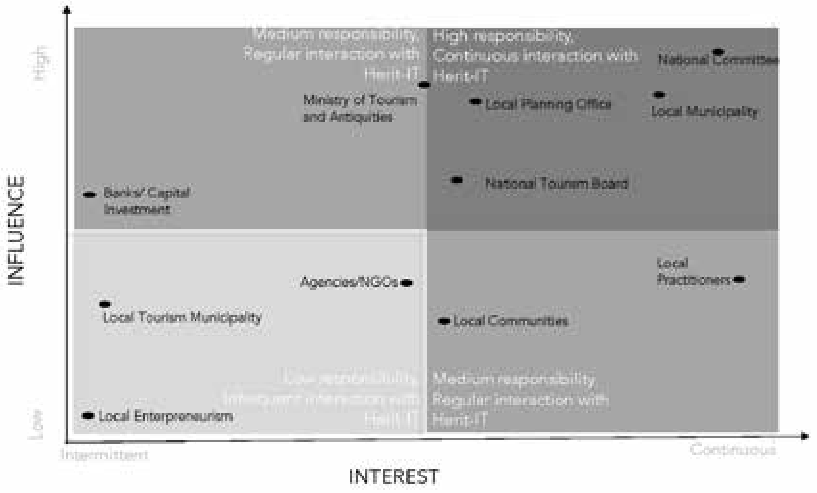


Fig.1. Mapping the stakeholders of the Herit-IT project according to Mendelow.

Understanding the dynamics of stakeholder interest and influence is essential for organizations seeking to navigate complex business environments and maintain positive relationships with the various parties involved in their operations. Stakeholders in the "Herit-IT Jordan Project" spanned a diverse spectrum. This encompassed heritage preservation organizations, government bodies responsible for cultural heritage, architectural firms involved in restoration and documentation, local communities with historical ties to the sites, and academic institutions contributing expertise. The roles and interests of each stakeholder group varied, and mapping these distinctions was essential for effective collaboration. The Stakeholder Matrix, as described by Mendelow [3], and adapted by Johnson and Scholes [4] provided a valuable tool for achieving this understanding and effectively managing stakeholder relationships.

3. Influences of cultural practices in data collection

The role of cultural practices and local norms in the process of data collection was of particular interest and had an impact of the data collection processes and types of information collected. In our field research for the Herit-IT Jordan Project, we encountered notable practices and challenges in data collection. Cultural differences were evident as we interacted with officials, emphasizing the importance of careful engagement with stakeholders [5].

3.1. Hierarchical practices

We noted in the fieldwork the importance of approaching and interacting with officials with great care. In most cases, the data required for analysis were understandably not directly collected by senior officials themselves. Instead, junior planning officers were responsible for data collection and analysis related to heritage buildings. These junior members demonstrated an in-depth understanding of the technical aspects of data collection and the utilization of software for information storage. They undertook the extensive task of creating photographic documentation of local heritage buildings over several months, organizing the collected photographs, and presenting them under the name of the local planning office. While we typically met with senior planning officials during international interest in their data, it was evident that a significant portion of the photographic documentation was carried out by these junior staff members.

The lack of awareness among senior officials about the practical aspects of data collection and technicalities of data management can lead to a communication gap. While contact with senior officials allows for broader access to information, the contributions of local junior staff on the ground, should not be underestimated. The cultural practice of mainly engaging with senior officials can result in a hierarchical collection of data, sidelining technical aspects, and potentially creating a knowledge transfer gap, between those who collect the data and those who manage it.

3.2. Insiders and outsiders to local culture

Another aspect we observed was the practice of local hospitality during interviews and data collection. In Arab culture, it is customary for hosts to provide a high level of care for visitors. While this practice adds a personal and welcoming touch to interviews, it sometimes blurs the line between informal discussions and formal interviews. The significance of non-verbal cues and ethnographical observations in interviews is well-documented, but including cultural practices such as offering beverages and food can both facilitate and complicate the interview process. It may ease the initial interaction but can also create a sense of obligation, affecting the balance of non-verbal interaction between the interviewer and interviewee. Discussions occasionally extended beyond formal settings, leading to ethnographical observations outside the defined research context. While this added depth to the understanding of the heritage aspects, it sometimes shifted the conversation away from technical information.

As international researchers, we were aware of our outsider status in the local culture. This was particularly evident in our interactions with local interviewees. In some cases, our suggestions and comments were met with disbelief, possibly due to the “outsider effect.” While our research team valued local expertise and sought to amplify the perspectives of local stakeholders, there was a sense that our status as outsiders limited our meaningful contributions to the project. Local interviewees expressed their skepticism, likely influenced by past experiences with international projects that left with collected data, leaving little for the local teams. These past experiences raised questions about data ownership and accessibility in internationally funded research projects in local areas.

3.3. Local requirements for collecting and managing digital data

Accessibility to data collected was sometimes compromised due to a lack of explicit guidelines for sharing data in the country, something we were not aware as outsiders to the local context. Additionally, the absence of local awareness regarding what constitutes heritage and its importance for the urban landscape often resulted in the neglect and deterioration of heritage buildings. While legislation aimed to protect heritage buildings was in place, it remained inactive. The activation of such legislation faced challenges due to the multitude of stakeholders involved, each with their own interests.

3.4. Technical issues of data collection and analysis

Issues with data collection were not limited to the local context. Software accuracy in data collection was another consideration. Building Information Modeling (BIM) and digital data collection techniques presented advantages and challenges. BIM offered a holistic approach to data inclusion, allowing for the incorporation of both technical and cultural information. However, the direct communication between BIM and point clouds posed difficulties, and manual processes were required to ensure comprehensive data integration. Figure 2 shows the process followed by the team's researchers to ensure the migration from data collection to the final digital Revit model.

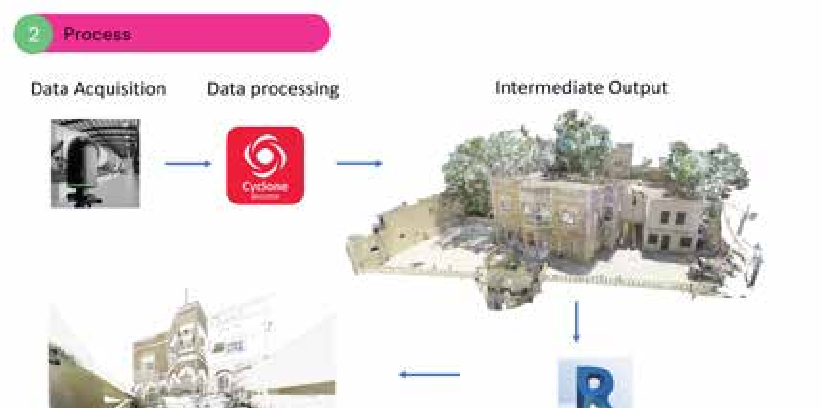


Fig.2. Process from data collection and point cloud to final Revit model. Image adapted from V. Cottella [6].

The project has created a new set of Building Information Modeling (BIM) objects specifically tailored to the traditional architecture heritage in Jordan. These BIM objects are designed to be practical tools for engineers and architects involved in interventions on heritage structures. They provide a standardized and efficient way to manage and represent heritage buildings. In addition, we have established a library of 3D models of exemplar buildings incorporated in a Centre of Excellence (CoE).

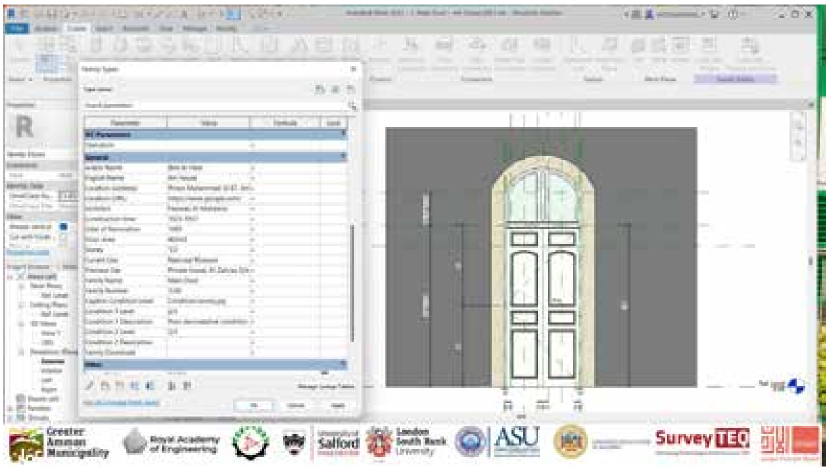


Fig.3. The final Revit model includes the option to alter dimentions and characteristics of objects. Image courtesy of V. Cotella [7].

3.5. Centre of Excellence (COE)

Perhaps the most important output of the project is the creation of a platform dedicated to the digital repository for conservation objects in Jordan, the Centre of Excellence (COE). This CoE is an online platform that holds the potential to foster cross-collaboration among architects, investors, developers, practitioners, academia, industry, and government. It serves as a virtual infrastructure, facilitating the exchange of knowledge and expertise in the field of digital technologies and heritage conservation. The CoE plays a pivotal role in ensuring the sustainability and continuation of our efforts in preserving Jordan's heritage. This repository could address the fragmented nature of currently available information, making it more accessible and consistent. The integration of technologies such as point clouds, 3D scanning, and BIM objects could be maximized when information on heritage sites is consistently managed.

The time-sensitive nature of heritage preservation is often neglected in the importance of timely data collection and management. Delayed collection of data, coupled with the fragility of heritage buildings, can result in damage and loss of knowledge. This issue can have economic implications, especially in areas where tourism development is rapidly advancing. In the absence of a publicly available digital repository, heritage buildings may be overlooked or damaged, affecting tourism and economic development. We also propose creating a protocol for data sharing on a digital platform, ensuring that data remains accessible. Additionally, awareness should be raised among governmental bodies, professionals, planners, architects, and industrial partners about the importance of sharing information for the benefit of cultural urban heritage.

To make the Centre of Excellence effective, it is necessary to cross-collaboration among diverse stakeholders, in heritage conservation with each contributing their unique expertise and perspectives. Academic institutions for example bring valuable research, expertise, and innovative approaches to heritage conservation. It is expected that their involvement in the Herit-IT Jordan Project has been instrumental in advancing the application of HBIM in traditional architecture preservation.

MODELS LIBRARY FOR HERITAGE IT JORDAN

A library of 3D models of exemplar buildings (Jordan heritage and traditional architecture)

The project aims at filling a gap in Jordan by applying digital technologies to support heritage conservation plans. This website contains a library of 3D

Fig.4. The online repository platform as part of the Centre of Excellence [7].

Industrial partners also play a vital role in implementing technology and ensuring that the project's outcomes have real-world applications. These partnerships are essential for the sustainability of heritage preservation initiatives. Government bodies and civic society organizations provide the regulatory framework, financial support, and community engagement necessary for the success of heritage conservation projects. The intention of the CoE is to also allow Government bodies and civic society organizations provide information of the regulatory framework, financial support, and community engagement necessary for the success of heritage conservation projects.

The Centre of Excellence (COE) stands as a symbol of innovation and collaboration. It enables stakeholders to share knowledge, develop best practices, and collectively work towards preserving and promoting Jordan's traditional architecture and cultural heritage.

4. Conclusion

In conclusion, the application of Heritage Building Information Modeling (HBIM) in the conservation and promotion of traditional architecture in Jordan represents a case study for the way ahead. As we look ahead, our commitment to preserving and promoting Jordan's rich cultural legacy remains unwavering. The Centre of Excellence (COE) creates the legacy of a platform that fosters collaboration, and knowledge exchange. The Herit-IT Jordan Project has successfully bridged innovation and history, leveraging HBIM as a powerful tool to protect our heritage. It is our hope that this collaborative approach will pave the way for the future of heritage preservation in Jordan.

5. Acknowledgments

This is an acknowledgement to the generous support for the project by the Royal Academy of Engineering, and the academic and industrial partners involved in the project.

Bibliography

1. Unesco, world heritage list, accessed at: https://whc.unesco.org/en/list/.
2. Aburamadan, R., Trillo, C., Udeaja, C., Moustaka, A., Awuah, K.G.B., Makore, B.C.N., *"Heritage conservation and digital technologies in jordan, digital applications in archaeology and cultural heritage"*, volume 22, 2021, e00197, issn 2212-0548, https://doi.org/10.1016/j.daach.2021.e00197
3. Mendelow, A. L., *"Environmental scanning--the impact of the stakeholder concept"* (1981). icis 1981 proceedings. 20. http://aisel.aisnet.org/icis1981/20.
4. Johnson, G. and Scholes, K. (1999), *"Expring crprat stratg, prentice hall europe"*.
5. Auramadan, R., Moustaka, A., Trillo, C., Makore, B.C.N., Udeaja, C., Gyau Baffour Awuah, K. (2021). *"Heritage building information modelling (hbim) as a tool for heritage conservation: observations and reflections on data collection, management and use in research in a middle eastern context. in: rauterberg, m. (eds) culture and computing. interactive cultural heritage and arts"*. hcii 2021. lecture notes in computer science, vol 12794. springer, cham. https://doi.org/10.1007/978-3-030-77411-0_1.
6. Cotella, V.A., *"From 3d point clouds to hbim: application of artificial intelligence in cultural heritage, automation in construction"*, volume 152, 2023, 104936, issn 0926-5805, https://doi.org/10.1016/j.autcon.2023.104936.
7. Trillo, C., Barba, S., Cotella, V., Ncube, C., Aburamadan, R., Moustaka, A., & Udeaja, C. (2021). "*Digital innovations for architectural traditional heritage conservation. in cities in a changing world: questions of culture, climate and design*" (pp. 252-265).
8. The online repository of 3d models library for heritage it Jordan, part of the centre of excellence: https://hitj.centroictbc.unisa.it/

Digital Twin and Applied Acoustics in Modern Theatres

Maria Cairoli

Politecnico di Milano, Dipartimento di Energia

maria.cairoli@polimi.it

Abstract

The main topic of the paper is the identification of a possible Bim Execution Plan (BEP) and Digital Twin (DT) use, applied to Acoustics in modern Theatres.

Reasons of this topic are explained to improve the control of the building process for theatres, linked to the modern evolution of the theatre space itself.

Nowadays theatres are often characterized by very flexible spaces that change layout, geometry, material claddings, according to the show set up. Also classical theatres, used in a modern way, become multipurpose rooms, supported by technological equipments and movable architectural elements.

The Bim Execution Plan and the Digital Twin represent a new opportunity to better control the the new dynamic space, introducing the theatre buildings in the industry 4.0.

Keywords: internet of things, indoor acoustics intelligent control, digital twin management

1. Introduction

In theatres designed or renovated as multipurpose rooms, the architectural flexibility of the space, together with the implementations of new technologies, plays an important rule, not only in the project phase of the building but also during its entire life cycle.

Theatres that are used for different activities, are often characterized by a huge number of seats (the seating capacity varies from 200 people to maximum 3000 people ca.) and different configurations that require a continuous control of the room acoustic response.

In a cinema configuration, for example, the optimal sound field range is different from that one requested during classical concerts: performing art spaces become dynamic spaces in continuous transformation, including a available acoustic response and movable architectural elements.

To define the optimum range of the main acoustic parameter, the so called Reverberation Time, according to the different activities, values suggested by the literature have to be achieved. The suggested RT values are function of the volume and the space use.

To learn how to develop thez design phase for a new theatre or for a renovation process of an existing Theater, an Integrated Design Process (IDP) is presented.

Acoustic, stage craft, multimedia and lighting consultants work together with the much more traditional actors of the process, such as architects and structures engineers.

An IDP for theatres is characterized by an interdisciplinary design approach that creates collaboration of the parties involved (Fig. 1).

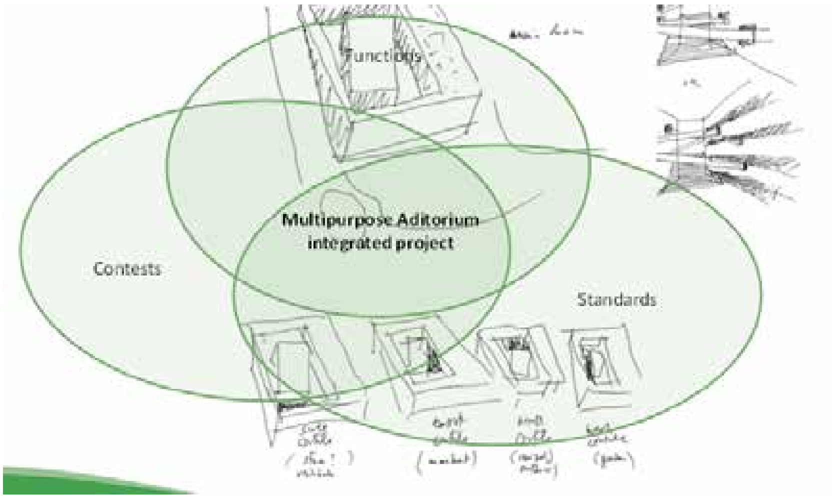


Fig. 1. IDP for multipurpose rooms.

The IDP establishes the cooperation between different professionals involved, which takes into account the interaction among the numerous factors involved. Traditionally the design of a theatre produced reports and 2D drawings that aimed at identifying the characteristics of the construction work. The design had to ensure:

- compliance with environmental, urban planning and cultural heritage and landscape protection regulations,
- high architectural and technical-functional quality,
- life cycle assessment and maintainability of the works.

Before the introduction of the BIM modeling, the design activities and related verifications came out through the progressive use of specific digital methods and electronic tools such as those of 2D drawing with dedicated software and 3D modeling only for specific areas by single consultants, including the virtual model for acoustic simulations.

The first Italian project ANIMA by Swiss architect Bernard Tschumi (an internationally renowned architect of Swiss origins), is shown as example of this process.

To better control IDP including a BIM modeling, as requested nowadays, an elaboration of the Building Execution Plan (BEP) is introduced, together with a second example, the Ristori theatre.

The drafting of the BEP defines the programmer objectives, the survey and the graphic restitution for each level of design (up to the executive phase), monitoring each phase of the building process till the verification and control operations that have to be carried out.

The BEP allows the introduction of a BIM methodology to be used in the most effective way and to create the basis for a Digital Twin.

2. Methods-Case study

The first Italian project ANIMA by Swiss architect Bernard Tschumi (an internationally renowned architect of Swiss origins), is shown as example of a Integrated Design Process.

The architect Bernard Tschumi presented the final project of ANIMA in a conference at the MAXXI museum in Rome in 2014 and immediately afterwards the work was exhibited at the Center Georges Pompidou in Paris, in an exhibition dedicated to the activity of Bernard Tschumi himself.

During the design phase, the flow of project ideas passed from one professional figure to another in a circular manner, to make every single proposal compatible with the needs of the other project participants. The circulation of an idea could occur several times before reaching its final development.

The circular process allows the project to advance with a motion that we can define as "helical" in all its phases, until reaching a more linear development in the more advanced phases of the project. In particular, aspects related to Room Acoustics are predominant over the aspects of building acoustics in the preliminary phase (Fig. 2).

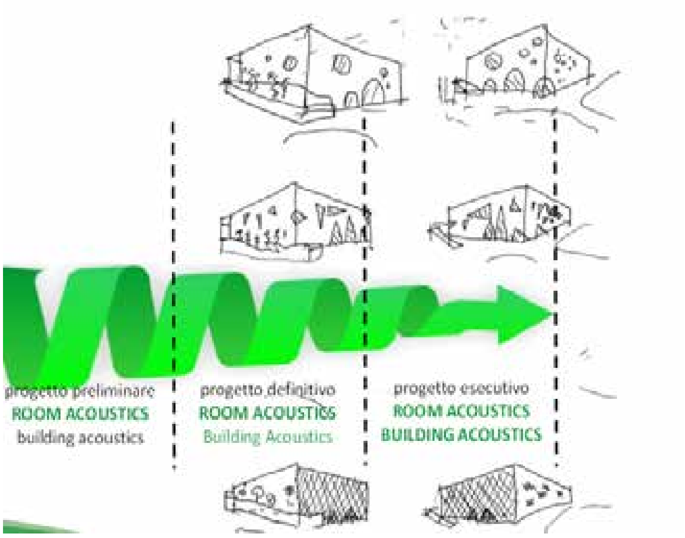


Fig. 2. Applied Acoustics development in a building process.

The ANIMA multifunctional auditorium, with a volume of approx. 18,000 m3, is in the shape of a "shoebox", the traditional shape that is best suited to optimizing the lines of visibility, i.e. the direct sound, and the sound field in all seating positions (Fig.3).

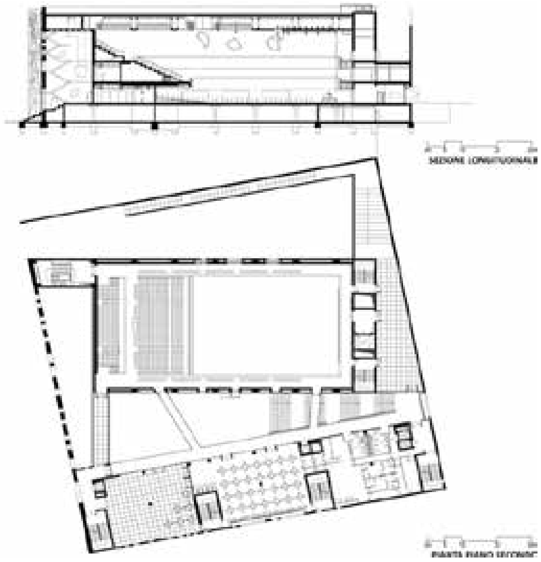


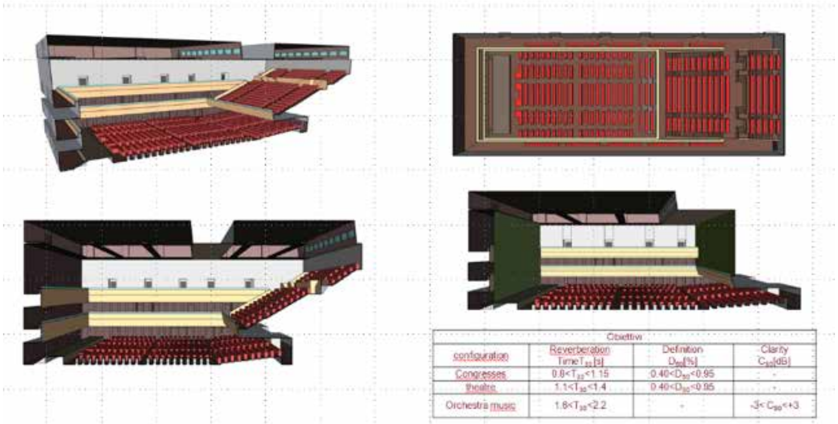
Fig. 3. ANIMA plan and transversal section.

The stalls is a flat surface, while other seats are distributed in two levels of lateral galleries, and in the part furthest from the stage, on steps in a balcony.

The parallelepiped shape allows to easily insert the single gallery at the end of the room, which can be excluded from the acoustically active volume when the capacity of the room is reduced from 1500 to approx. 1100 spectators. In fact, a large mobile wall can be lowered from the ceiling to separate the two sectors, reconfiguring the room into a smaller one.

The room is approximately 29 m wide, with a maximum depth of approximately 45 m and a height of 17 m.

In the figure 4 the sketchup model is represented, which was imported with some further simplifications into the dedicated software for predictive acoustic analysis.



Obiettivi			
configuration	Reverberation Time T_{30} [s]	Definition D_{50}[%]	Clarity C_{80}[dB]
Congresses	$0.8<T_{30}<1.15$	$0.40<D_{50}<0.95$	-
theatre	$1.1<T_{30}<1.4$	$0.40<D_{50}<0.95$	-
Orchestra music	$1.8<T_{30}<2.2$	-	$-3<C_{80}<+3$

Fig. 4. Virtual model for acoustic simulations.

The set-up system is made up of mobile platforms, with variable heights, which give the possibility of distributing the audience in the room in a different way from time to time, in steps or on a level, positioning the removable and stackable seats on them.

The side walls are covered with a “transparency wall”, a wall transparent to sound, i.e. a metal mesh behind which variable acoustic elements are hidden: reflective panels that can be partially or totally covered by heavy, sound-absorbing fabrics. This acoustic-architectural solution is repeated up to the level of the second gallery which runs all around the room; from this level up to the ceiling the side walls are sound-absorbing. The back, stall and gallery walls are also sound-absorbing. The surface behind the front stage is sound-reflecting instead.

Sound-absorbing panels arranged vertically (baffles) approximately 1 m high, are hung from the ceiling, placed on a towed device which allows an “open” arrangement, useful for making the ceiling sound-absorbing, or “closed”, leaving the intrados of the ceiling exposed of the cover, as a sound-reflecting surface.

The acoustic evaluation method and the parameters considered are those presented in ISO 3382-1 including the Reverberation Time (RT), the Intelligibility Index (STI), the Clarity Index (C80) and the Definition Index (D50).

The input data are determined by the acoustic absorption coefficient of the surfaces that enclose the confined space under examination, which vary depending on the finishing materials and their geometric shape.

The outputs indicate a room characterized by “alive” and “enveloping”, “warm” natural acoustics, necessary in unamplified musical performances. Thanks to the movable elements, by unwinding the curtains and redistributing the baffles on the ceiling, the sound field can increase clarity and reduce the reverberation time, to satisfy different needs, especially the increase in speech understanding, even amplified.

To better control IDP including a BIM modeling, an elaboration of the Building Execution Plan (BEP) could assume particular importance.

The drafting of the BEP can define the programmer objectives, the survey and the directives of graphic restitution for each level of design (up to the executive phase), monitoring each phase of the building process.

The BEP becomes useful to improve a series of digital tools in the project phase, making them interact and making them available in order to facilitate the collaboration between the numerous subjects involved in the process, and ensure the synchronization of the workflow up to the management.

The BEP allows the introduction of a BIM methodology to be used in the most effective way and to create the basis for a Digital Twin.

A second example is introduced as a specific case of restoration process for theatres, for which the main contents of the BEP are summarized as it follows:

- BIM software to be used during the project
- identification of goals
- experience of the team,
- analysis of the current situation of the theatre,
- objectives and uses of information models,
- information modeling and definition of LOINs,
- contextual management of the collaborative design phase.

The example is referred to the Ristori theatre, a baroque theatre of the nineteen century, that has had alternating various changes of use until its last renovation, which brought it back to its former charm. The renovation design identifies also the ancient architectural and acoustic quality.

The renovation process made it compatible with the various configurations and sound field requirements of a multi-purpose room, characterized by a mutable audience distribution, variable acoustic response and different stage equipments layouts.

The theatre is in the city of Verona, with a capacity of 600 seats ca. The restoration and complete renovation of the building was completed in 2012, some 30 years after its closure. The intervention aimed to keep the external appearance of the building and the hall as similar as possible to how it was in the past, while for the other spaces, such as the foyer, a new and complete refurbishment was carried out, with a more modern taste.

The conditions in which the theatre was at the time of the starting of the renovation process, were very bad (Fig. 5).

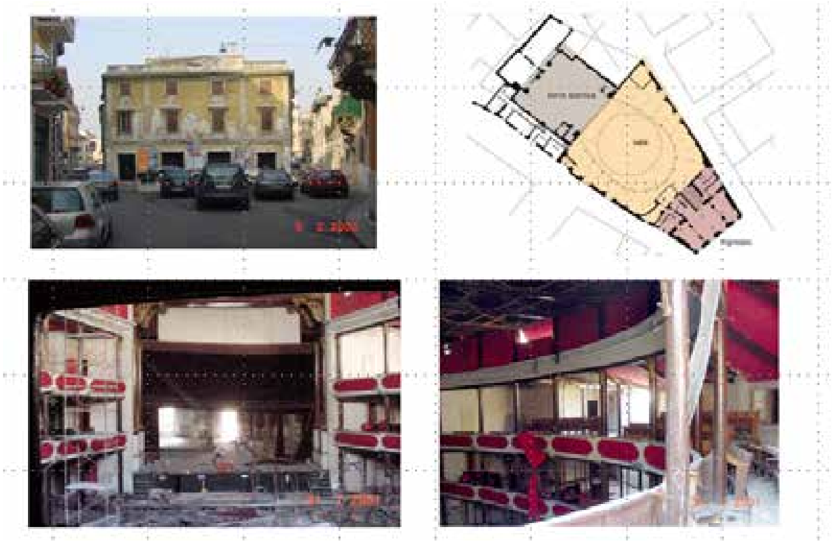


Fig. 5. The Ristori hall before the renovation process.

The designer Mario Cibic aimed to give back to the city a space capable of hosting artistic and cultural events of a different nature, a versatile place with high aesthetic and functional qualities, a point of light aimed at the neighborhood, and at the whole city. Ideally it could offer specificity and flexibility, and at the same time become, when necessary, an empty box, equipped to accommodate events to be set up according to needs.

Four main hall configurations were designed:

- Italian opera theatre conformation: according to the original nature of the theatre;
- Concert Hall configuration: an acoustic shell is set on stage and the floor,
- Central space configuration: provides for the function of the stage in the centre of the stalls
- Black Box configuration: the theatre space becomes an empty box

To control the room acoustics in the main hall the optimal range for the Reverberation Time was established (Tab. 1).

Configuration	Optimal range RT[s]
Congress hall	0.9>RT<1.1
Drama theatre	1.1>RT<1.3
Opera theatre	1.3>RT<1.6
Concert Hall	1.6>RT<1.9
Black box	0.9>RT<2.3

Tab. 1. Reverberation Time optimal range for the main configurations and the virtual model

The Reverberation Time variation is achieved varying both the seats quantity in the hall and the scenic elements, from configuration to configuration.

A BEP was suggested to be followed as represented in the table below (Tab. 2):

Identification of goals and contents present	To transform the theatre in a multipurpose room
Previous skills and experience of the team	Team with multi-year experience in Theatre restoration process including: -theatre planning consultant -acoustic consultant -lighting designer -energy consultant -Cam consultant
Survey/analysis of the current situation of the theatre	geometric information obtained using a 3D laser scanner acoustic measurements structural check electrical system check
BIM software to be used during the project and its versions	Authoring tool
Objectives and uses of information models, how data is shared	loadable objects for theatres (columns, parapets, armchairs, etc) data is shared trough IFC
Compliance with standards;	Collection of the all standards required

Tab. 1. Ristori theatre BEP

To achieve a successful IDP, a BIM methodology was suggested to be one of the most important support factors, together with a rigorous organization of work in the digital field, that provides for the drafting of the BEP.

As farther development, a BIM model supported by a BEP created a Digital Twin to optimize the use of the building in all the possible configurations during the entire theatre life cycle, implementing the data exchange, between the sensors that identify the room configurations and the acoustic database created by measurements.

The BIM model is the repository where the quantity of surfaces and materials are stored and extracted for the digital twin visualizations. By using VPL (visual programming language) compatible with the BIM authoring tool (e.g. Dynamo), the Digital Twin can provide an image of the building, with a specific RT, C80 and STI value for the corrent configuration.

The IoT building facilities' sensors help in fact to recognize the theatre configuration. First, raw data from the sensors is processed to identify the configuration. Once the configuration is identified, the data can be used to identify the referred acoustic quantities to be visualized in the Digital Twin.

3. Conclusion

The proposed procedure, starting from a IDP analysis, though the BEP elaboration and a Digital Twin visualization improves the control of the set up configurations and the optimization of the acoustic conditions, introducing a IoT approach for stagecraft equipment, linking them to the developed Building Information Model of the Hall.

The DT allows, in general, the visualization of the various possible configurations inside the multipurpose space, in real time, during the organization phase of the show set up, including acoustic properties. As a virtual representation of the real hall, showing objects and stagecraft systems, the DT uses data from sensors (IoT devices) in order to visualize the room layouts changes and the corresponding acoustic parameters.

Specialists, musicians and artists involvement is reduced to setup the single show acoustic field, optimizing time and costs. The procedure can be extended to other physical quantities including their effects on the acoustic response itself.

Bibliography

Cumo f., S. Sferra A., Pennacchia E. (2019) "*Patrimonio edilizio strumenti digitali integrati per il progetto esecutivo*"- rivista Techne n.18 ISSN 2239-0243

Ciribini A. L. C., Ventura S. M., Paneroni M., (2015), *"BIM methodology as an integrated approach to heritage conservation management"*, WIT Trans. Built Envron., vol. 149, pp. 265–276, 2015

Decreto Legislativo 31 marzo 2023, n. 36 *Codice dei contratti pubblici in attuazione dell'articolo 1 della legge 21/06/2022, n. 78*, GU Serie Generale n.87 del 13-04-2023 - Suppl. Ordinario n. 14

Tronchin L., Merli F., Manfren M., (2021), "*On the acoustics of the Teatro1763 in Bologna*", Applied Acoustics, vol. 172, p. 1-9, Elsevier, doi: 10.1016/j.apacoust.2020.107598

Mazzarella L., Cairoli M., (2018), "*Petrarca Theatre: A case study to identify the acoustic parameters trends and their sensitivity in a horseshoe shape opera house*", Applied Acoustics, vol. 136, p. 61-75, Elsevier doi: 10.1016/j.apacoust.2018.02.018

Rizzarda C., Gallo G., (2020), *"Bim Execution Plan, Strumenti per un piano di gestione informativa agile"*, Tecniche Nuove editore, Milano.

Oreni D., Brumana R., Georgopoulos A., Cuca B., (2013), *"HBIM for conservation and management of built heritage: towards a library of vaults and wooden beam floors, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences"*, Volume II-5/W1, 2013, XXIV International CIPA Symposium, 2 – 6 September 2013, Strasbourg, France,doi:10.5194/isprsannals-II-5-W1-215-2013

Ryan L. Solnosky, (2017), *"Integrated Structural Processes on Innovative Multidisciplinary Projects Supported by Building Information Modeling"*, J. Archit. Eng., 2017, 23(2): 05016004

Balzani M., Suppa M., (2020), *"Integrated survey procedures: a methodological approach for documentation and repre-*

sentation applied to Emilia-Romagna theatres", Materials Science and Engineering 949 (2020) 012011, IOP Publishing, doi:10.1088/1757-899X/949/1/012011

THEDE, J.; BOYTS, N.; TEEL, J.; BUTLER, K.; BARGAS, E. ; ROTH, A. *"Building information modeling (BIM) automation for architectural acoustics, mechanical noise calculation"* J. Acoust Soc Am 2022, 151 p.A56-A56

RIZAL, R., HIKMATYAR, M. INVESTIGATION *"Internet of Things (IoT) Device using Integrated Digital Forensics Investigation Framework (IDFIF)"*. J. Phys. Conf. Ser. 2019, 1179, 012140.

WONG, J.K.W.; GE, J.; HE, S.X. *"Digitisation in facilities management: A literature review and future research directions"*. Autom. Constr. 2018, 92, 312–326.

RAFSANJANI, H.N.; GHAHRAMANI, A. TOWARDS *"Utilising internet of things (IoT) devices for understanding individual occupants' energy usage of personal and sharedappliances in office buildings"*. J. Build. Eng. 2020, 27, 100948.

WANG, M.; ZHANG, G.; ZHANG, C.; ZHANG, J.; LI, C. *"An IoT-based appliance control system for smart homes."* In Proceedings of the IEEE 4th International Conference on Intelligent Control and Information Processing (ICICIP), Beijing, China, 9–11 June 2013; pp. 744–747.

DIGITAL TWINS FOR IOT APPLICATIONS: "*A Comprehensive Approach to Implementing IoT Digital Twins*". Available online: https: //pdf4pro.com/view/digital-twins-for-iot-applications-oracle-5b4880.html (ac-cessed on 6 June 2021).

LAVINIA CHIARA TAGLIABUE AND IBRAHIM YITMEN *"Special Issue Cognitive Buildings"*. Appl. Sci. 2022, 12.

CHUNG, S.W.; KWON, S.W.; MOON, D.Y.; KO, T.K. "*Smart facility management systems utilising open BIM and augmented/virtual reality*". In Proceedings of the 35th International Symposium on Automation and Robotics in Construction (ISARC2018), Berlin, Germany, 20–25 July 2018.

Metaverse, Digital Twins, and the Evolution of Smart Cities

Wikan Danar Sunindyo
Institut Teknologi Bandung, Indonesia;
wikan@itb.ac.id

Abstract

This paper delves into the convergence of three transformative concepts: the metaverse, digital twins, and smart cities. It explores how the fusion of these technologies and ideas is reshaping urban environments, enhancing citizen experiences, and enabling more efficient, sustainable, and connected cities. By investigating the relationship between these innovations, we uncover the potential for a new era in urban dzevelopment.

Keywords: Metaverse, Digital Twin, Smart City

1. Introduction

The metaverse is an evolving digital realm that offers users a virtual, interconnected, and immersive experience in which they engage with both one another and digital content in real-time. This intricate landscape blends elements of virtual reality (VR), augmented reality (AR), and the internet to establish a communal digital space. Beyond its roots in gaming and entertainment, the metaverse spans a wide spectrum of applications, including virtual meetings, educational experiences, and collaborative workspaces. Key technologies propelling the metaverse's development encompass VR/AR devices, blockchain technology, facilitating asset ownership and transactions, and the innovative concept of non-fungible tokens (NFTs), which represent unique digital assets within this expansive digital frontier.

Digital twins are essentially digital copies or depictions of physical items, systems, or surroundings. These replicas can mimic tangible entities in a virtual realm, providing a comprehensive and engaging portrayal of their real-world counterparts. Digital twins find applications across different fields such as manufacturing (for enhancing procedures), urban planning (in the creation of city models), and healthcare (for personalized patient simulations and diagnostics). Their precision is upheld by utilizing data obtained from sensors, IoT devices, and various other origins, ensuring accuracy and delivering immediate insights.

Smart cities represent urban environments that employ advanced technology and data-driven strategies to ameliorate the quality of life, optimize operational efficiency, and foster sustainability among their inhabitants. These technologically advanced municipalities harness an array of key technologies, including the Internet of Things (IoT) for comprehensive data collection from diverse urban systems, data analytics, and artificial intelligence (AI) for informed and data-centric decision-making, as well as 5G networks to ensure robust and low-latency connectivity.

The advantages conferred by smart cities encompass enhanced transportation systems characterized by real-time data integration, predictive maintenance, and optimized traffic flow. Furthermore, smart cities realize advanced energy management through the integration of renewable energy sources, smart grids, and demand response systems. Healthcare services are elevated through telemedicine, remote patient monitoring, and data-driven healthcare resource allocation. These innovations are integral components of an overarching paradigm shift in urban planning, promoting a holistic approach to create more livable, efficient, and sustainable urban environments.

2. Understanding the Metaverse

The metaverse is a multifaceted and immersive digital environment distinguished by several key features. Firstly, it offers a virtual and immersive experience, enabling users to engage with computer-generated environments and interact with other users in real-time. This interaction often results in a profound sense of presence and immersion, blurring the boundaries between the physical and digital realms.

Secondly, the metaverse is an interconnected landscape comprising various virtual spaces, worlds, or environments.

These spaces may exhibit diverse themes, purposes, and rules, yet they are seamlessly linked, facilitating fluid transitions for users moving between them.

Another defining aspect is the role of user-generated content. In the metaverse, users often possess the capability to create and contribute content, including virtual objects, avatars, environments, and experiences. This empowers users with a high degree of agency and creativity, enriching the metaverse's ever-evolving tapestry.

Lastly, the metaverse is persistent and continually evolving. It endures and undergoes continuous transformation, even when users are absent, reflecting ongoing user interactions, updates, and the addition of new content. This dynamism contributes to the metaverse's ability to remain relevant and captivating over time.

3. Introduction to Digital Twins

Digital twins are virtual replicas or representations of physical objects, systems, or environments. They serve as digital counterparts that mirror the real-world entities in detail. Digital twins use data from various sources, including sensors, IoT devices, and other data streams, to simulate and model the physical objects or systems. This technology enables real-time monitoring, analysis, and interaction with physical assets in a virtual environment.

Concept and Types of Digital Twins:

1. **City Digital Twins:** City digital twins replicate entire urban environments, including infrastructure, buildings, transportation systems, and public spaces. They provide a comprehensive view of a city's operations, allowing for data-driven decision-making in urban planning and management.
2. **Building Digital Twins:** Building digital twins represent individual structures, such as houses, offices, or factories. They capture data on a building's architecture, systems (e.g., HVAC, electrical), and occupancy, facilitating energy efficiency optimization, space management, and maintenance planning.
3. **Infrastructure Digital Twins:** Infrastructure digital twins focus on critical infrastructure components like bridges, roads, and utility networks. These twins help monitor structural health, detect defects, and predict maintenance needs to ensure safety and longevity.

Role of Digital Twins in Urban Development:

Digital twins play a crucial role in urban development by offering the following benefits:

1. **Enhancing City Planning and Design:** Digital twins enable city planners and architects to create accurate 3D models of urban environments. These models help visualize proposed changes, test different scenarios, and optimize designs for efficiency, aesthetics, and sustainability.
2. **Predictive Maintenance for Infrastructure:** Infrastructure digital twins monitor the condition of critical assets in real-time. By analyzing data from sensors, they can predict maintenance requirements, reducing downtime, and extending the lifespan of infrastructure.
3. **Improving Urban Resilience:** Digital twins help cities prepare for and respond to disasters and emergencies. They can simulate disaster scenarios, test evacuation plans, and identify vulnerabilities, ultimately enhancing a city's resilience and disaster preparedness.
4. **Data-Driven Decision-Making:** Digital twins provide a wealth of data that city officials can leverage to make informed decisions. From traffic optimization to resource allocation, data-driven insights contribute to more efficient and sustainable urban development.
5. **Efficient Resource Management:** By monitoring resource consumption (e.g., water, energy) in real-time, digital twins enable cities to optimize resource allocation, reduce waste, and lower operational costs.
6. **Community Engagement:** City digital twins can engage citizens by providing them with access to real-time data and simulations. This fosters transparency, empowers residents to participate in urban planning, and strengthens the sense of community ownership.

In summary, digital twins are powerful tools that empower urban planners, engineers, and policymakers to create smarter, more resilient, and sustainable cities. Their ability to model, simulate, and monitor urban environments is instrumental in shaping the cities of the future.

4. The Synergy: Metaverse Meets Digital Twins

Digital twins serve as a foundational element for creating immersive metaverse experiences:

1. **Creating Immersive, Realistic Virtual Cities:** Digital twins of entire cities provide a detailed and accurate foundation for metaverse environments. Users can explore virtual replicas of real cities with a high degree of realism, from iconic landmarks to everyday urban life.
2. **Integration of Real-World Data:** Digital twins integrate real-time data from various sources, such as IoT sensors, traffic cameras, and weather stations. This data ensures that the virtual city reflects real-world conditions, including traffic patterns, weather events, and energy consumption.

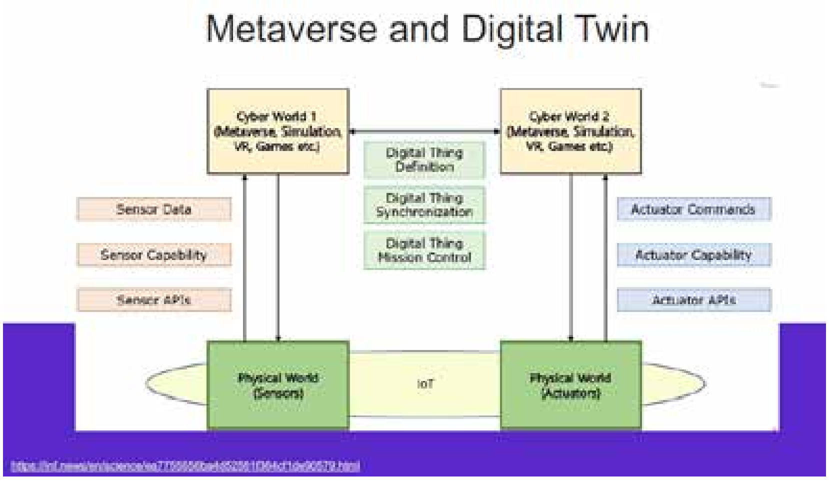


Fig. 1. Metaverse and Digital Twin.

Digital Twins Enhanced by the Metaverse:

The metaverse enhances digital twins by adding dynamic and interactive elements:

1. **Real-Time Interactions with City Data:** In the metaverse, users can interact with the digital twin's real-time data. For example, they can check live traffic updates, monitor air quality, or view energy consumption patterns within the virtual city.
2. **Citizen Engagement and Participation:** The metaverse provides a platform for citizen engagement and participation in urban development. Citizens can virtually attend town hall meetings, contribute ideas for city improvements, and collaborate with urban planners within the metaverse.

Case Studies: Smart Cities Leveraging the Metaverse and Digital Twins:

1. **Singapore's Virtual Singapore:** Singapore's "Virtual Singapore" is a pioneering example of a digital twin-powered metaverse experience. It offers a 3D replica of the city-state, which can be explored and analyzed by urban planners, researchers, and citizens. Real-time data is integrated to monitor various aspects, including traffic, weather, and energy usage. This metaverse-enabled digital twin helps in urban planning, disaster management, and public engagement.
2. **Dubai's Digital Twin for City Planning:** Dubai is using digital twins to create a metaverse experience that allows users to explore future city developments. This immersive experience helps city officials, developers, and

residents understand urban projects before they are built. The metaverse component adds interactivity, such as the ability to provide feedback on proposed designs.

3. **Los Angeles' 3D Urban Modeling:** Los Angeles has developed a digital twin of the city that includes detailed 3D models of buildings and infrastructure. This digital twin serves as a foundation for metaverse experiences, enabling urban planners to simulate and visualize various urban development scenarios. It also fosters community engagement by allowing residents to explore and provide input on city projects within a metaverse environment.

These case studies showcase how the convergence of digital twins and the metaverse is transforming the way cities are planned, experienced, and developed. By leveraging the power of these technologies, smart cities can enhance citizen engagement, improve urban resilience, and make more data-driven decisions for sustainable urban development.

5. Smart Cities and the Digital Transformation

Definition and Characteristics of Smart Cities:

Smart cities are urban areas that utilize technology and data-driven solutions to enhance the quality of life for their residents, improve efficiency in urban operations, and promote sustainability. They exhibit several key characteristics:

1. **Technological Integration**: Smart cities leverage advanced technologies to collect, process, and analyze data from various urban systems, creating a connected and intelligent urban environment.
2. **Data-Driven Decision-Making**: Data is at the core of smart city initiatives, enabling city officials and planners to make informed decisions, optimize resource allocation, and address urban challenges effectively.
3. **Efficiency and Sustainability**: Smart cities aim to maximize resource utilization while minimizing waste, resulting in efficient services, reduced environmental impact, and sustainability practices.
4. **Quality of Life**: Residents of smart cities benefit from improved services, infrastructure, and urban planning, leading to a higher quality of life in terms of safety, convenience, and overall well-being.
5. **Innovation and Collaboration**: Smart cities foster innovation by collaborating with technology companies, startups, and research institutions to develop and implement cutting-edge solutions.

Technologies Underpinning Smart Cities:

Several technologies underpin the concept of smart cities:

1. **IoT (Internet of Things) and Sensor Networks**: IoT devices, equipped with sensors and connectivity, collect real-time data from various urban systems, including transportation, energy, and environmental monitoring.
2. **Data Analytics and AI (Artificial Intelligence):** Advanced data analytics and AI algorithms process the vast amounts of data generated by IoT devices. They uncover insights, detect patterns, and enable predictive modeling for informed decision-making.
3. **Connectivity and 5G:** High-speed connectivity, such as 5G networks, facilitates real-time data transmission, enabling seamless communication between IoT devices and central control systems.

Benefits of Smart Cities:

1. **Efficiency and Sustainability:** Smart cities optimize resource use, reducing energy consumption, traffic congestion, and waste, leading to a more sustainable and eco-friendly urban environment.
2. **Improved Quality of Life:** Enhanced urban services, including efficient transportation, healthcare, and public safety, result in an improved quality of life for residents.
3. **Economic Development:** Smart cities attract investment, businesses, and talent by fostering innovation and providing a conducive environment for economic growth.

4. **Safety and Security:** Advanced surveillance and emergency response systems enhance safety and security in smart cities, reducing crime rates and improving disaster preparedness.
5. **Environmental Benefits:** Reduced emissions, improved waste management, and green infrastructure contribute to a cleaner and healthier environment.
6. **Resource Optimization:** Smart city technologies optimize resource allocation, such as water and electricity, resulting in cost savings for both governments and residents.
7. **Enhanced Mobility:** Smart transportation systems offer efficient public transit, traffic management, and mobility-as-a-service solutions, reducing congestion and commute times.

In summary, smart cities harness technology and data to create urban environments that are more efficient, sustainable, and livable. These cities offer a wide range of benefits, from economic growth to improved environmental stewardship, ultimately aiming to enhance the well-being of their residents and drive progress in the digital age.

6. Metaverse-Enabled Smart Cities

How the Metaverse Can Enhance Smart Cities:

1. **Real-Time Urban Data Visualization:** The metaverse can enhance smart cities by providing real-time data visualization tools. Citizens and city officials can access and interact with data on various urban aspects, such as traffic, air quality, and energy consumption, within the metaverse. This visualized data helps in making informed decisions and understanding urban dynamics better.
2. **Virtual Public Services and Events:** The metaverse can host virtual public services and events that engage citizens and improve accessibility. For instance, public meetings, town halls, and government services can be conducted in a virtual environment, enabling broader participation and convenience for residents.

Digital Twins as the Backbone of Smart Cities:

1. **IoT Integration and Real-Time Monitoring:** Digital twins serve as the backbone of smart cities by integrating IoT sensors and devices. These digital replicas continuously collect and analyze real-time data from various urban systems, allowing city officials to monitor infrastructure, traffic, environmental conditions, and more. This integration enables proactive maintenance and improved resource allocation.
2. **Predictive Analytics for Urban Planning:** Digital twins facilitate predictive analytics by modeling different urban scenarios. With historical and real-time data, they can forecast trends, potential issues, and infrastructure needs. This predictive capability aids in long-term urban planning, helping cities prepare for future challenges and opportunities.

Case Studies: Smart Cities Leveraging Metaverse and Digital Twin Technologies:

1. **Singapore's Virtual Singapore:** Singapore's "Virtual Singapore" project utilizes digital twin technology and offers a metaverse experience. It allows residents to explore a virtual representation of the city, access real-time data, and participate in urban planning discussions. This initiative enhances citizen engagement and enables better-informed decision-making.
2. **Los Angeles' Digital Twin for Infrastructure:** Los Angeles employs digital twins for its infrastructure, including roads, bridges, and utilities. By integrating real-time data from IoT sensors and combining it with a metaverse interface, city officials can remotely inspect and monitor infrastructure conditions. This approach enhances maintenance efficiency and ensures safety.
3. **Amsterdam's Urban Digital Twin for Mobility:** Amsterdam uses a digital twin focused on mobility to improve transportation systems. By integrating data from public transit, traffic management, and environmental monitoring, the city can optimize traffic flow and reduce congestion. This digital twin is accessible through the metaverse, enabling citizens to interact with real-time traffic information and contribute to traffic management

decisions.

These case studies demonstrate the practical implementation of metaverse and digital twin technologies in smart cities. By combining the metaverse's immersive experiences with digital twins' data-driven insights, cities can engage citizens, make more informed decisions, and create more efficient and resilient urban environments.

7. Conclusion

Recap of Key Findings:

The convergence of the metaverse, digital twins, and smart cities represents a dynamic and transformative force in urban development. Here are the key findings:

1. **Metaverse and Digital Twins Synergy**: The metaverse and digital twins, when integrated, create a powerful symbiotic relationship. Digital twins provide the data foundation for immersive metaverse experiences, while the metaverse enhances digital twins with real-time interaction and visualization.
2. **Smart Cities as the Beneficiary**: Smart cities are at the forefront of this integration, benefiting from enhanced urban planning, real-time monitoring, and predictive analytics. The synergy between these technologies promises more efficient, sustainable, and engaging urban environments.
3. **Citizen Engagement and Participation:** The metaverse empowers citizens to actively engage in urban development, providing a platform for collaboration, feedback, and virtual participation in city planning and governance.
4. **Data-Driven Decision-Making:** Digital twins and the metaverse provide cities with a wealth of real-time data, enabling data-driven decision-making, efficient resource allocation, and improved urban resilience.
5. **Sustainability and Quality of Life:** The integration of these technologies fosters urban sustainability by optimizing resource use and reducing waste. This, in turn, enhances the quality of life for urban residents, offering safer, cleaner, and more efficient urban environments.

Emphasizing the Transformative Potential:

The transformative potential of the metaverse, digital twins, and smart cities when combined cannot be overstated. This integration has the power to redefine the urban experience, making it more connected, data-driven, and engaging. It empowers citizens to actively shape their cities and contributes to more sustainable and resilient urban development.

Closing Thoughts on the Future of Urban Development:

The future of urban development lies at the intersection of the physical and digital worlds. As the metaverse, digital twins, and smart cities continue to evolve and converge, we can anticipate:

1. **Hyperconnected and Inclusive Cities:** Urban environments will be hyperconnected, offering seamless transitions between physical and digital realms. Cities will become more inclusive, ensuring that all residents can access and benefit from digital services.
2. **Data-Driven Sustainability:** Sustainability will be a top priority, with real-time data informing resource management and eco-friendly practices.
3. **Personalized Experiences:** Residents will enjoy personalized urban experiences, from tailored transportation options to customized entertainment and services.
4. **Enhanced Quality of Life:** The integration of these technologies will result in a higher overall quality of life, characterized by efficient public services, reduced congestion, cleaner environments, and vibrant communities.

In conclusion, the future of urban development is an exciting journey into a world where cities are not just physical spaces but dynamic, data-rich ecosystems that adapt to the needs and aspirations of their residents. The metaverse, digital twins, and smart cities will play a pivotal role in shaping this future, making urban living more sustainable, resilient, and enjoyable for all.

Acknowledgement:

I acknowledge the supporting of ChatGPT in producing this paper.

Bibliography

SH Supangkat, "*Metaverse & Digital Twin Cyber to Physical System Real World and Virtual World*", 2022.

Anne Galang, "*Smart Cities and Big Data*".

Daniel Dietrich, "*State of Play of Open Data in Berlin*".

Robertus Theodore, Satu Data Indonesia, Tenaga Ahli KSP.

KemenPanRB, "*Perumusan Kebijakan Koordinasi Penerapan SPBE*",2021.

Dirjen Aptika Kemenkominfo, "*Guideline Masterplan Smart City*", 2021.

SH Supangkat, "*The Roles and Challenges of Regulation in Digital Transformation*".

Turbaningsih O, Mutaharah U, Saputra P, "*The Study of Potential Application of Modular Construction in the Development of Indonesia's New Capital City*", Jurnal Teknik Sipil, 2022.

Artificial Intelligence in Digital Twin for the built environment

Claudio Tomazzoli

Computer Science Department, University of Verona, Italy;

claudio.tomazzoli@univr.it

Abstract

Articial Intelligence (AI) is a powerful tool for digital twins in the built environment because it provides the means to automatically achieve advanced analytics, predictive capabilities, optimization, decision support, autonomous control, and improved occupant experiences. We show also with examples of how AI can applied to energy saving problems as well as security related tasks.

Keywords: Artificial Intelligence, Genetic Algorithm, Support Vector Machine

1. Introduction

AI (Artificial Intelligence) plays a crucial role in enhancing the capabilities and effectiveness of digital twin technology in the built environment. By leveraging AI techniques, digital twins can become more intelligent, responsive, and capable of providing valuable insights and predictions.

Here are some key areas where AI contributes to digital twins in the built environment:

1. **Data Analytics:** AI algorithms enable advanced data analytics and pattern recognition within digital twins. By analyzing vast amounts of data collected from sensors, IoT devices, and other sources, AI can identify patterns, anomalies, and correlations. This helps in identifying performance issues, predicting maintenance needs, and optimizing operational efficiency.
2. **Predictive Maintenance:** AI algorithms can analyze real-time and historical data from digital twins to predict maintenance requirements for various building systems and infrastructure assets. By identifying potential failures or performance degradation in advance, AI-powered digital twins enable proactive maintenance, reducing downtime and optimizing asset lifecycle.
3. **Energy Optimization:** AI algorithms integrated with digital twins can analyze energy consumption patterns, weather data, and occupancy information to optimize energy usage within buildings and other built environment assets. AI can identify energy-saving opportunities, recommend optimal control strategies, and enable intelligent energy management systems.
4. **Simulation and Optimization:** AI-powered digital twins can simulate various scenarios and optimize building or infrastructure performance. Through machine learning algorithms, digital twins can learn from historical data and recommend improvements to achieve energy efficiency, occupant comfort, and overall sustainability goals.
5. **Decision Support:** AI can assist decision-making by providing insights and recommendations based on the analysis of data within digital twins. AI algorithms can process complex data sets, perform simulations, and generate actionable recommendations to support stakeholders in making informed decisions related to building design, infrastructure planning, and asset management.
6. **Autonomous Systems:** AI-powered digital twins can enable autonomous control of systems and processes within the built environment. By combining AI with digital twins, buildings and infrastructure assets can adapt to changing conditions, optimize operations in real-time, and improve overall efficiency and performance.
7. **Occupant Experience:** AI can enhance the occupant experience within the built environment by leveraging data from digital twins. AI-powered systems can learn occupant preferences, adjust environmental conditions (such as lighting and temperature), and provide personalized services, enhancing comfort and productivity.

AI significantly enhances the capabilities of digital twins in the built environment. By leveraging AI algorithms, digital twins can provide advanced analytics, predictive capabilities, optimization, decision support, autonomous control, and improved occupant experiences. As AI technologies continue to advance, the integration of AI with digital twins will continue to drive innovation and transform the way buildings and infrastructure are designed, operated, and managed.

In the following, we present some artificial intelligence techniques applied to energy saving problem and security camera positioning in critical infrastructures.

2. AI Applied: Automatic Synthesis of best practice in energy consumption

The problem of automatic synthesis of best practice can be defined as the problem of extracting the rules of correct behaviour observing the installation than behaves in the most efficient way, so we have two different sub-problems. To induce rules we have to face the problem of finding the correct installation from which learn the rules and then we have to try and extract rules from data of this plant.

A. Finding the better performing plant

First of all we have to find the one that behaves best, but not all installations are the same: in one home we can have one fridge and forty lamps and one oven, such in a normal flat, while in one other we can have two fridges and two ovens and twenty lamps, such in a house with a garden. Moreover in an office we can find more printers than in another in which we can find several coffee machines, even with the same number of computers.

We therefore cannot have only one "best" situation, but we will define several "template" plant which will be taken as examples for all similar installations, so we have to define a procedure to define when a plant is similar to another so that they can be considered as belonging to a common group. Which is to say, we have to define a clustering for these installations.

For this purpose, clusters of similar installations may be created and examined, and rules that are acceptable for all the plants in a particular group could be extracted. Accordingly, the method of best practice extraction relies on three main steps:

1. Clustering the set of available plants;
2. Finding the better performing one on each cluster;
3. Making the synthesis of the rules for the set of measures of these plants, so that these rules can be applied to other similar installations .

Clustering the set of available plants

All devices can be considered belonging to a class, such as printer, coffee machine, television, fridge. Considering all devices in all plants in our system, we can define a set C = {c1, . . . , cn} of classes of all devices. The feature vector representation of an plant pj can be defined therefore as a vector whose i−th component is the number of devices of that plant belonging to the i − th class, leading to a representation in which a plant can be considered a point in a n−dimensional vector space, as shown in Figure 1 below (representing only three classes . being 3-dimensional).

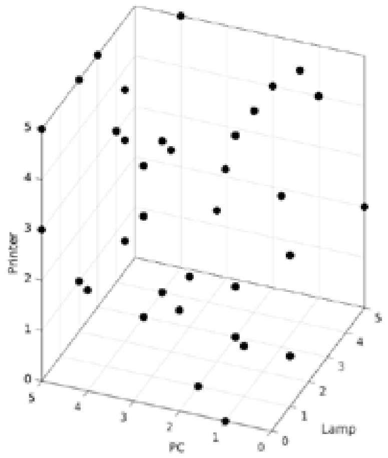


Fig. 1. Example of feature representation of plants in a 3-dimensional vector space.

Consider system *S* with three installations *p1, p2, p3* where in plant p1 there are two printers, ten computers and one coffee machine, in *p2* there are one fridge, two televisions and one washing machine and one oven, while in *p3* we have five computers, one coffee machine, one fridge and one printer.

Our classes will be *C = {Printer, Computer, Fridge ,Coffee-machine, Television, Washing-machine, Oven}* and the vector representation of our installations will be

p1 = (2,10,0,1,0,0,0)

p2 = (0,0,1,0,2,1,1)

p3 = (1,5,1,1,0,0,0)

Once we have our feature representation of our systems, we can apply the well known *k-means* clustering algorithm to find our group of similar systems, as shown in Figure 2.

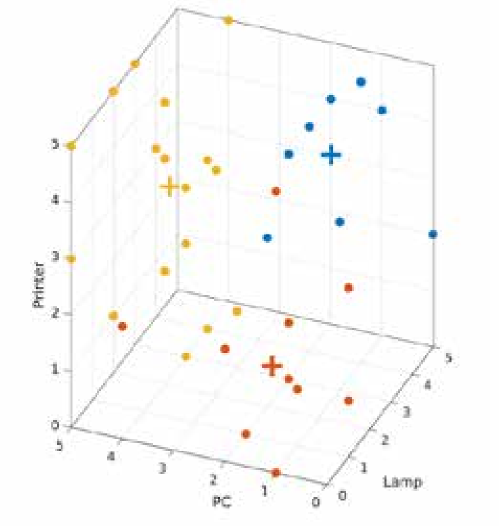


Fig. 2. Result of 3-means clustering algorithm over the input set of Figure 1.

We can now find the best performing plant, one per cluster, as the installation whose consumption are minimal with respect to all other plants in the same cluster over a given interval of time.

Finding the better performing one

Finding the best performing plant, one per cluster, is a straightforward task and does not require any machine learning technique. This may be done given only the energy bill over a few months, but it can also be per- formed in detail using the energy data collected over time from the appliances in the plant. The desired best performing plant is simply the installation whose consumption is minimal with respect to all other plants in the same cluster over a given interval of time.

Making the synthesis of the rules

Machine learning techniques and rule-based methods such as association rule learning are particularly useful in cases where hidden relationships among vari- ables in large data sets have to be discovered.

Data collected from devices are relative to the power consumption of the device itself and the time at which the data has been collected. Without lack of generality we can consider the data to be a dataset $D = \{d1,...,dk\}$ in which every element has the form $di = \{plant, device, power, time\}$.

Defining a *configuration* of a plant at a given time as the set of the status of all devices of a plant at that time, we can extract from that dataset all the configurations of a plant in a given interval of time (say, a week).

The times at which occur a change in the configuration of the plant are defined relevant moments.

An association rule is an implication of the form $X \quad Y$, *where* $X \quad I, Y \quad I$, and $X \quad Y = \emptyset$.

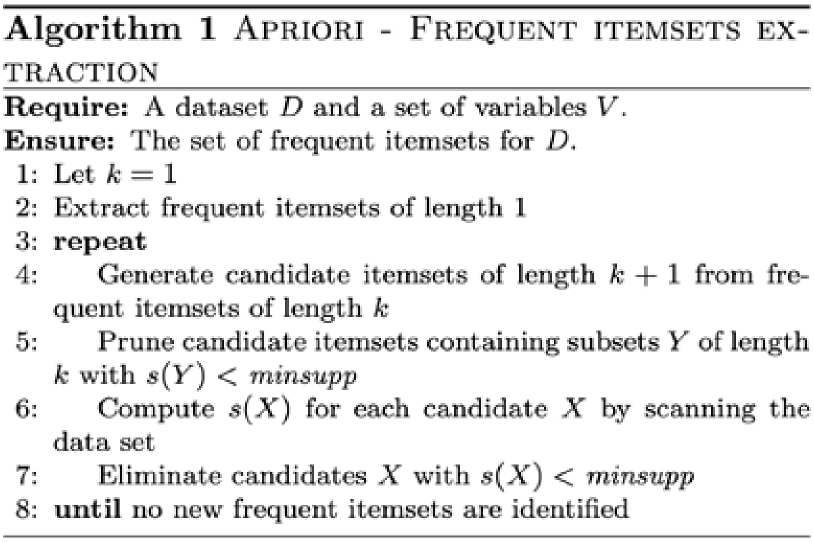
The association rule $X \; Y$ holds in the text D with confidence c if c% of transactions in D that contain X also contain Y. The rule $X \quad Y$ has support s if s% of transactions in D contain $X \quad Y$.

Mining association rules is to find all association rules that have support and confidence greater than or equal to the user-specified minimum support (called minsup) and minimum confidence (called minconf).

So the problem of finding antecedents and consequent is analog to the problem of mining association rules.

The Apriori Algorithm is an influential algorithm for mining frequent itemsets for boolean association rules. It proceeds by identifying the frequent individual items in the database and extending them to larger and larger item sets as long as those item sets appear sufficiently often in the database.

Algorithm 1 reports the pseudo-code of the procedure followed by Apriori algorithm in frequent itemset extraction



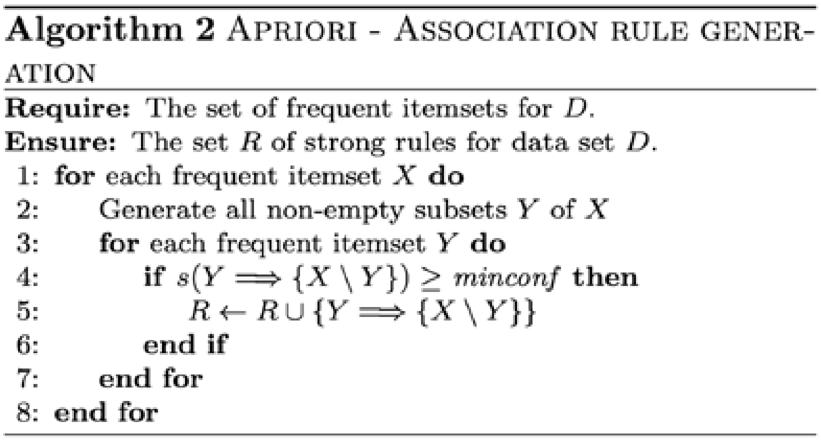
Algorithm 1 APRIORI - FREQUENT ITEMSETS EXTRACTION

Require: A dataset D and a set of variables V.

Ensure: The set of frequent itemsets for D.

```
Let $k = 1$
Extract frequent itemsets of length 1
repeat
    Generate candidate itemsets of length $k + 1$ from frequent itemsets of length $k$
    Prune candidate itemsets containing subsets $Y$ of length $k$ with $s(Y) < minsupp$
    Compute $s(X)$ for each candidate $X$ by scanning the data set
    Eliminate candidates $X$ with $s(X) < minsupp$
until no new frequent itemsets are identified
```

The pseudo-code of rule extraction procedure followed by Apriori algorithm is reported in Algorithm 2.



Algorithm 2 Apriori - Association rule generation

```
Require: The set of frequent itemsets for $D$.
Ensure: The set $R$ of strong rules for data set $D$.
for each frequent itemset $X$ do
    Generate all non-empty subsets $Y$ of $X$
    for each frequent itemset $Y$ do
        if $s(Y \implies \{X \setminus Y\}) \geq minconf$ then
            $R \leftarrow R \cup \{Y \implies \{X \setminus Y\}\}$
        end if
    end for
end for
```

3. AI Applied: Automatic detection of device type using an inexpensive sensor

This is a problem strictly related to one above faced, one often presents in Digital Twin: is the digital representation really a "twin", meaning is it correctly representing its physical counterpart?

In our case, the method above explained strongly rely upon the fact that the model represents the reality, i.e. the composition of the installation at any given time shall be given for granted.

However, environments are not immutable and energy load change over time sometimes in an unpredictable way; a trivial example being an office in which vending machines and printers may be added or removed without previous notice and without updating their digital representation. In Figure 3 we show an example of office electric load layout, in which most of the devices are attached to plugs (in this case smartplugs) and therefore can be easily connected to other smartplugs without any notice made to the monitoring system.

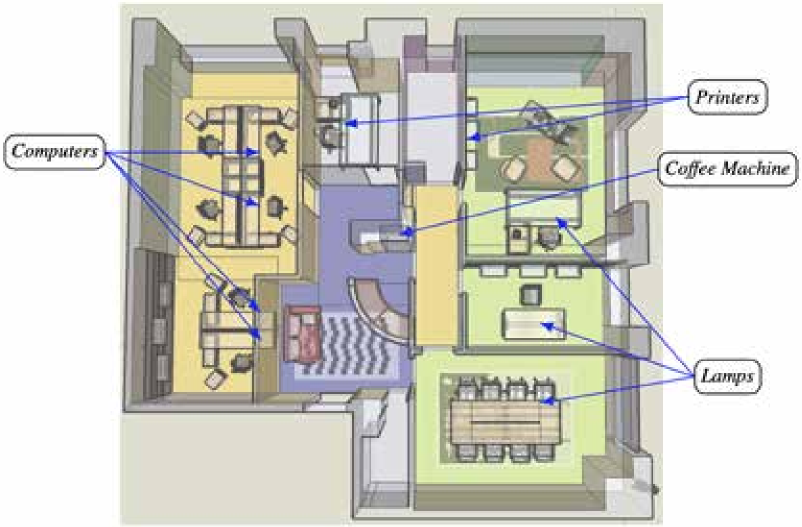


Fig. 3. Example of office electric load layout.

The constant update of the connected device database is a time consuming task and the process is likely to be prone to a number of errors increasing with time.

This lead to the risk of invalidating the whole method based on best practices, so a solution to the problem of having the correct representation of what are the actual loads in a plant is in order.

A possible way of solving the problem is using machine learning to automatically detect and recognize a device based on measurements. Smartplugs are nowadays quite cheap, although the can measure only active power without considering the reactive part, which play an important role whenever the load is not purely resistive. Nevertheless, we propose a method that make use of this inexpensive measure.

Consider the active power consumption of a device measured at several moments. This can be viewed as a function of power over time, as expressed in Figure 4

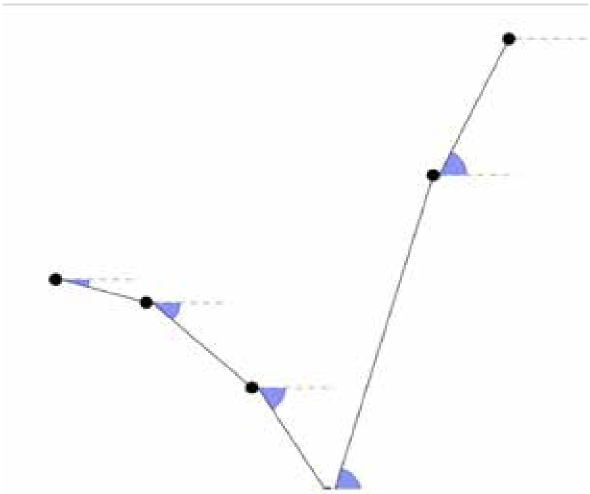
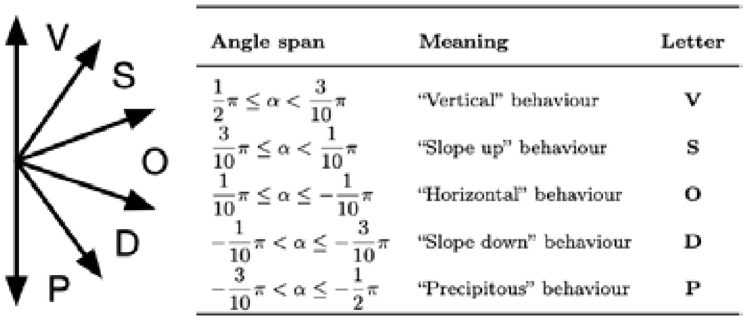


Fig. 4. Active power consumption curve over time.

We give an alphabetical representation of the power in a given interval of time representing only the angles between one measure and the following one.

We use the angle because we want to be insensitive to scaling; a big fridge and a small fridge are similar devices, with similar power figures, only the bigger one is scaled because it consumes much more power; the same applies to lights and all other devices. We establish a mapping function from two consecutive measure to a letter of the alphabet (as in Figure 5). Note that the letter “O” denoting an horizontal behaviour have a mnemonic meaning in Italian language, where the word horizontal is translated as “orizzontale”.



Angle span	Meaning	Letter
$\frac{1}{2}\pi \leq \alpha < \frac{3}{10}\pi$	“Vertical” behaviour	V
$\frac{3}{10}\pi \leq \alpha < \frac{1}{10}\pi$	“Slope up” behaviour	S
$\frac{1}{10}\pi \leq \alpha \leq -\frac{1}{10}\pi$	“Horizontal” behaviour	O
$-\frac{1}{10}\pi < \alpha \leq -\frac{3}{10}\pi$	“Slope down” behaviour	D
$-\frac{3}{10}\pi < \alpha \leq -\frac{1}{2}\pi$	“Precipitous” behaviour	P

Fig. 5. Graphic representation of alphabetic mapping.

In this way, the power curve of a device in a given interval of time shall be represented in the form of a simple sequence of characters, like for example

OOOOVOOOOOPOOOOOOOOOVOOOOPO

After the transformation, a sequence of energy measures is a sequence of strings like the one above, or in other terms the measures over a given time frame are transformed in sequence of words, something like a text footprint of the device under inspection. Here algorithms from the well known field of text mining may be applied to extract which devices are similar: devices with many words in common are more similar than ones with few.

Here we can apply algorithms from the well known field of text mining to extract which devices are similar; devices with many words in common are more than similar than ones withfew.

The bag-of-words model is a simplifying representation used in natural language processing and information retrieval. In this model, a text is represented as an unordered collection of words, disregarding grammar and even word order. Using this model we shall have bag of energy words for each load, an example of which is given in the table below:

	Computer	Printer	Fridge
OSDOVP	1	2	O
OVOPO	1	0	0
OVDO	2	2	2
ODOSO	0	0	1

The intended meaning is that, for instance, the alphabetic translation of the power curve of a printer contains two times the character sequence OSDOVP, and two times the character sequence OVDO while the sequence ODOSO is contained only in text fingerprint of the fridge. The bag-of-words model is employed in methods of document classification where the (frequency of) occurrence of each word is used as a feature for training a classifier.

The feature representation of a device di (denoted by di) is a n- dimensional vector whose j-th component dij, with $1 \le j \le n$, is the number of occurrences of energy word wj in the textual footprint of di. As an example, given the set of acceptable energy words $W = \{OVSO, OVDO, OVOPO, ODOSO, OSDOVP\}$, the feature representation of the three devices Computer (*d1*), Printer (*d2*) and Fridge (*d3*) in Table above are

d1 = 02101, d2 = 02002, d3 = 02001

Being based on the assumption that word positions in a text are irrelevant, we choose a well known text classifier to achieve our goal.

The Naive Bayes text classifier is a simple probabilistic classifier which is based on Bayes theorem with strong and naive independence assumptions. It is one of the most basic text classification techniques and is based on the assumption that the position of the words in a text is irrelevant, which is exactly our case. We use a Naive Bayes text classifier to classify devices: given a set of known devices, which can grow over time, we can classify unknown devices by comparing them with known (labeled) ones, thus automatically detecting device type.

4. AI Applied: Automatic positioning of security cameras

It is extremely hard to to define a formal method to achieve optimal positioning for security cameras, nevertheless goal are quite easy to define:

- we want coverage, maximized where the risk of an area is higher;
- we want to minimize overall cost, so that
    - minimize adding infrastructure such as poles
    - reuse existing poles and walls

Therefore, once there is a solution, it is easy to evaluate its performance.

We present the case study of a critical infrastructure: the harbour of a small island in the Mediterranean Sea, Ventotene Island,

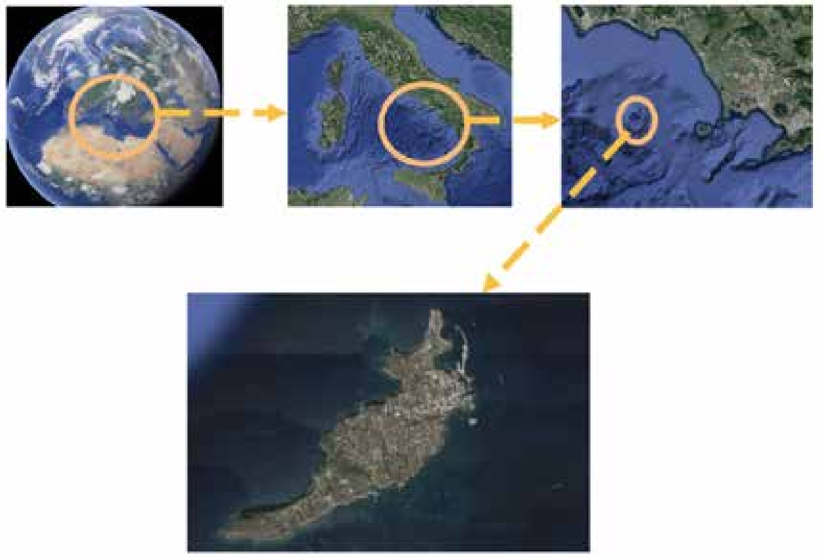


Fig. 6. Ventotene Island.

We present the use of genetic algorithm to solve the problem at hand.

Genetic algorithms

Genetic algorithms (GAs) are a specific type of algorithm from the much broader family of algorithms known as evolutionary computation, one of the main principle of computational Intelligence which in turn, is a subset of Artificial Intelligence. GAs and other evolutionary algorithms are optimization algorithms, inspired by traditional biological evolution, which use mechanisms such as reproduction, mutation, recombination, and selection to achieve the solution.

An "individual" in GAs represents a possible solution to the problem. In the case of the camera positioning problem an individual can be fully de- scribed by the radius of the circle covered by the camera and a list of points *{(x0,y0,z0),(x-1,y1,z1),...(xn,yn,zn)}* which are of the points the cameras have to be positioned.

A "population" is a collection of individuals each having a different list of points.

Initially, the individuals are selected randomly which leads to a large search space but as the program begins to converge, the individuals are quite similar leading to a small search space likely near the optimum [3].

The main advantage of a genetic algorithm is having multiple semi-optimal solutions which breed with each other to eventually obtain the strongest traits from each solution. Unlike other optimization techniques,

GAs allow jumping from a semi-optimal solution to a completely different yet more optimal solution [4]. This is important for our problem which, like the circle covering/packing one, may have a large (or even continuum) number of optimal solutions. Traditional GAs have three steps "Selection", "Crossover", and "Mutation". Selection trims the population to select the strongest individuals for crossover. The "strength" or "fitness" of an individual is determined by a user specified objective function, often called a fitness function.

Crossover involves combining traits of two or more individuals to create a new one. It is often the case that crossover results in a new individual (child) which has a higher fitness than its predecessors (parents).

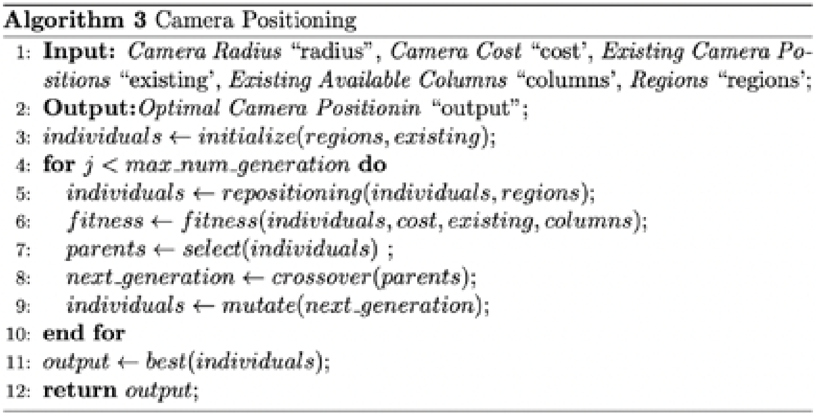
The final step, "Mutation", involves slightly perturbing a candidate solution. This is done randomly to members of the population and serves to add additional variance. This way, the program does not get stuck at a local minimum and instead is able to search the full solution space.

Positioning main algorithm

We think a genetic algorithm can be of help in our case, however for automatic camera positioning problem it is necessary to add an additional step to the traditional approach.

Since a requirement of the problem is that the solution shall cover almost all the polygon, this a constraint that shall be enforced. The proper place where this can be done is the fitness function in which there will be a penalty related to the amount of uncovered area. This way, individuals which fail to cover the region will be gradually removed leaving only the ones which cover most of the polygon. The problem with this approach is that it might discard a lot of good individuals and therefore threaten the ability of the algorithm to converge; on the contrary a slight movement of the center of a circle in the individual results in better covering of the surface, therefore adding to the performance of the whole system. Given all this, we decided to follow the clever approach of [4] and introduce a "reposition function". In essence this function fixes individuals to cover the region as best as possible. The program finishes when there aren't enough individuals in the population to breed anymore or the number of maximum generations is reached.

Our approach is therefore expressed in Algorithm 3, whose functions will be detailed in following paragraphs.



```
Algorithm 3 Camera Positioning
Input: Camera Radius "radius", Camera Cost "cost', Existing Camera Positions "existing', Existing Available Columns "columns', Regions "regions';
Output: Optimal Camera Positionin "output";
$individuals \leftarrow initialize(regions, existing)$;
for $j < max\_num\_generation$ do
    $individuals \leftarrow repositioning(individuals, regions)$;
    $fitness \leftarrow fitness(individuals, cost, existing, columns)$;
    $parents \leftarrow select(individuals)$ ;
    $next\_generation \leftarrow crossover(parents)$;
    $individuals \leftarrow mutate(next\_generation)$;
end for
$output \leftarrow best(individuals)$;
return $output$;
```

Initialization

An individual is initialised by randomly generating an initial guess of circle centers within the polygon region. To create the first generation we need to supply an initial guess of how many circles the final solution will have. We start with randomly generate 20 circles and discarding the ones that cover the region with less than a determined thresholding value.

Repositioning

We adopt the strategy employed in [5], which computationally solved minimal radius circle covering: we use the BroydenFletcherGoldfarbShanno (BFGS) algorithm to find layouts of circles which maximise the area of the region covered. BFGS is a quasi-Newtonian method which iteratively finds a stationary point. The main advantage of BFGS over other optimisation algorithms is that the exact Hessian matrix is not needed and instead can be approximated. This is valuable since finding the Hessian for non-linear problems like circle covering is often non-trivial . The required input for BFGS optimisation is an initial guess (x1 , x2 , . . . , xn) and a function. In this case, the tuple is a flattened version of the centers of the agent (x0, y0, x1, y1, . . . xn, yn) and the function returns the area of intersection between the agent and the region.

After BFGS is applied, we test that the individual is indeed covering the region. However, not every one is repositionable. In fact many will not be, for example, if the optimal solution for a cover is 15 circles a layout with 14 circles will never cover the region. Additionally, sometimes, even a layout with 15 circles may not cover the region after BFGS is applied. The individuals which are not repositionable are discarded. If a sufficient starting population is given this is not an issue.

Fitness Function

The fitness function is determined by several factors:

- Area of intersection between the circles and the outside of the region,
- Area of self-intersection between the circles,
- Total cost: cost × circles the cost of the camera multiplied by the number of circles.
- Existing Camera Positions
- Existing Available Columns

We defined the risk areas to be divided in "tiles" so that each tile can be evaluated: A risk prize coefficient per covered tile is defined depending on the risk coefficient of the area the tile belongs to.

The total coverage prize will be the sum of all the prizes of covered areas and it will add to the fitness of a solution, while the total cost will be deducted from the fitness itself. Therefore we will have a mean to evaluate a solution.

Selection

As for selection the bottom x% of individuals with respect to the fitness evaluation are deleted from the population. We have used 20% nevertheless the number can be changed depending both on the size of the initial population and the desired rate of convergence: bigger initial populations can sustain higher deletion rates.

Crossover

Crossover functions in genetic algorithm can be changed on a problem by prob- lem basis. In our case breeding individuals so that their desirable traits are conserved, which is preferable, means selecting circles from parents so that the surface covered is maximal.

Thus it does not make sense to randomly select circles from both of the parents and add them to the child as it will result in a configuration which is not similar to either parent. In particular, if a crossover function is not selected carefully, a consequence could be having all the circles on only half the region.

Furthermore, this configuration will likely not be fit for repositioning.

In essence, the aim is to construct a child which takes circles of parents which are locally close and selects one of them. In practice, this is done via Voronoi diagrams. Given (p1,p2,...pn) points, sometimes called seeds, a Voronoi diagram on the plane is a partition of the plane into n sub-regions such that each sub-region Si contains only points which are closer to pi than to any other point.

The way the breeding works is by first constructing Voronoi diagrams for both parents.

Then consider the Voronoi diagram from the first parent. Stack onto it the center points of second parent. Iterate through the regions of the Voronoi diagram. If the region does not contain a point from the second parent, append to the circle list of the first child, the point which generated the current region. If instead the region contains points from the second parent randomly select either all the points from this second parent contained in the region, or the point from first parent. Append these points to the circle list of the first child.

In this case we iterate through half the length of the population, randomly select two individuals and breed them. Each bred pair produces two children. After iterating through the entire population the children and parents are added back into the population and repositioned as indicated in Algorithm 3.

Mutation

The final step in the algorithm is to "mutate" random individuals in the population. Among the several possibilities we believe the best ones are removing cameras and moving cameras. As we like the mutation to be effective, when it involves the removal of cameras it will not remove at random but the "worst" ones will be selected. This leads to the definition of "worst" which in our case is twofold: a camera is "bad placed" if it covers a small part of the region in which it is placed as well as if it highly overlaps with others. The overlapping is the intersection between the covered circle of the camera and the covered circles of the other cameras of the individual: the bigger the size of the overlapping, the worst is the camera. When the mutation is about moving camera, it will shift a random one by a random specified amount. The mutation rate for removal is .1 where as the mutation rate for moving the circle is 0.2. Again, these mutation rates can be changed based on the size of the initial population.

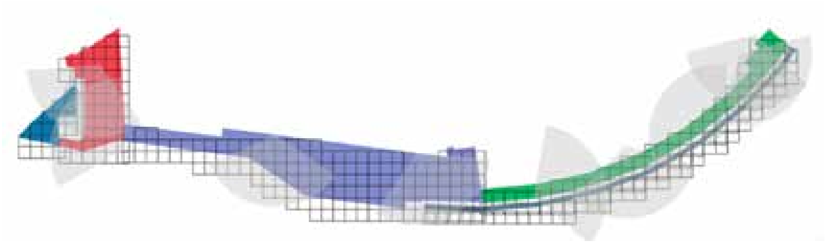


Fig. 7. The result of the automatic positioning

5. Conclusion

Artificial Intelligence is going to gain importance in digital twins for the built environment because it can help automate important tasks such as advanced analytics, predictions, optimizations, autonomous control, and improved occupant experiences. We have presented a few artificial intelligence techniques applied to energy saving problem and security camera positioning in critical infrastructures, however these are only a small number of the technologies AI comprises.

Bibliography

1. Sofia Agostinelli, Fabrizio Cumo, Giambattista Guidi, and Claudio Tomazzoli, *"Cyber- physical systems improving building energy management: Digital twin and artificial intelligence,"* ENERGIES, 2021.
2. Claudio Tomazzoli, Simone Scannapieco, and Matteo Cristani, *"Internet of things and artificial intelligence enable energy efficiency,"* JOURNAL OF AMBIENT INTELLIGENCE AND HUMANIZED COMPUTING, 2020.
3. K. Deb. *"A population-based algorithm-generator for real-parameter optimization. Soft Computing"*, 9:236 – 253, 2005.
4. Juan J. Flores, Jose Martinez, and Felix Calderon. *"Evolutionary computation solutions to the circle packing problem. Soft Computing"*, 20:1521 – 1535, 2016.
5. Claudio Tomazzoli, Simone Scannapieco, *"Machine learning for energy efficiency: Automatic detection of electric loads from power consumption"*. In Proceedings of the 2017 AEIT International Annual Conference, 2017.
6. Claudio Tomazzoli, Matteo Cristani, Erisa Karafili, and Francesco Olivieri, *"Non- monotonic reasoning rules for energy efficiency,"* JOURNAL OF AMBIENT INTELLIGENCE AND SMART ENVIRONMENTS, vol. 9, pp. 345–360, 2017.

Unlocking the past from space

Jolanda Patruno

RHEA GROUP; Via di Grotte Portella, 28, Palazzo Clorofilla, Scala C, 00044 Frascati, Italy

j.patruno@rheagroup.com

Abstract

Due to the pandemic, according to UNESCO's World Heritage Committee, as of early April 2021, 71% of the 1,121 World Heritage sites had been closed, while 18% were only partially open. The unprecedent experience of the pandemic changed, and is still changing, the way we look at, understand, and visit our Heritage. What future and which technologies can reshape awareness, preservation, and fruition? Moreover, the climate change challenge poses an urgent need for action in preserving cultural sites. To date, the Copernicus family and the ESA Contributing Missions can support the management of Heritage during emergencies, as well as the mapping, monitoring, preservation of cultural heritage as a daily routine, but how this information can be integrated with different data sources? The engagement of multi- and inter-disciplinary communities to fill the gap between experts (remote sensing, Cultural Heritage managers, AI experts, social scientists, civil protection, and actors from impact sectors) represents a key factor for strengthening the communication and the collaborations between EO experts and Heritage managers as well as the connection between the data providers and the end-users /site managers. How interdisciplinarity can support the generation of processes and practices for the use of technologies for Heritage site monitoring and preservation? Remote sensing plays a fundamental role in GIS applications by providing essential data for spatial analysis, visualization, and decision-making, enhancing GIS capabilities by capturing information from a distance, allowing for a broader perspective and coverage of large areas.

Keywords: Archaeology, cultural heritage, remote sensing, GIS, interdisciplinarity, Copernicus

1. Introduction

In recent years, satellite EO (Earth Observation) technology has represented a primary source of geo-information to support national and local authorities and conservation institutions in managing and monitoring Heritage sites. Applications include preservation actions for valorization plans, sustainable tourism processes, buried features identification, as well as anthropogenic and natural risk monitoring such as looting and climate change effects on cultural landscapes, from early warning and rapid mapping to post-disaster analysis and damage assessment [1]. The Copernicus Programme can play a big role in helping the process of monitoring cultural heritage sites and cultural landscapes as well as supporting their associated management.

Also, the unprecedented set of recent and new commercial space missions that will be available in the coming years will increase the potential of satellite data as an essential information for monitoring Cultural and Natural Heritage worldwide. Base mapping, habitat inventorying, assessment and land motion measurements are only a few examples of the state-of-the-art applications offered by EO in this field [2].

The integration with other space and non-space applications, such as navigation, GIS (Geographic Information System), drones and citizen science to cite a few, can represent a significant step forward towards the development of efficient and cost-effective tools to "observe", map and monitor protected areas worldwide. Monitoring, safeguarding, and protecting our Cultural Heritage (CH) requires actions at multi-disciplinary level, application of novel technologies and involvement of technical experts, CH managers, local authorities and it may also require actions from tourists and private citizens. However, the large set of stakeholders often lack a clear and collective understanding of the underlying issues, and they need help for planning and implementing efficiently suitable preservation and mitigation measures.

2. Remote Sensing for Cultural Heritage

The rationale behind the remote analysis of archaeological features is based on the possible presence of discriminate surface indicators not visible at the ground level. Since the early 20th century, a series of remote observations of the ground took place, by using different sensors and platforms, with the scope of documenting the existing archaeological features through aerial acquisitions [3]. After the pioneering attempt of the archaeologist Giacomo Boni, who in 1898 took some photographs from a military balloon tied to the ground (Figure 1, left), the potential of aerial observation was then recognized after the World Wars.

In fact, the Royal Air Force aerial campaigns trying to collect information about ground troops movements and camps, also revealed the presence of extra-urban ancient structures. The originator of aerial photography for archaeology was the Jesuit missionary and explorer Antoine Poidebard, who, provided with logistical support by the French Air Force, clocked up thousands of flying hours over the desert steppes of Syria and along the Mediterranean coast as far as Algeria and Tunisia (Figure 1, right).

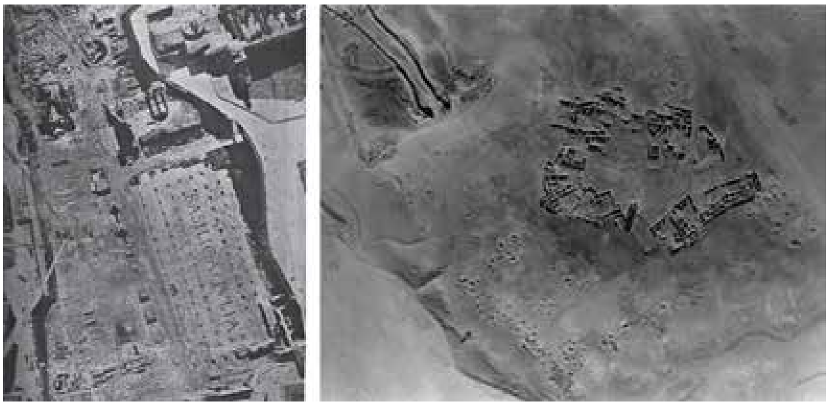


Fig. 1. Left: aerial view of Roman Forum from a military balloon tied to the ground. Right: ancient structures detected in Royal Air Force acquisitions, World War II.

Since the year 2000, Remote Sensing Archaeology has seen many innovative archaeological applications and encountered some emerging and challenging issues analysed and described in a large number of studies [4],[5] . By using satellite passive and active sensors, space stations, space shuttles, aircrafts, unmanned aerial vehicles (UAV) and drones, archaeologists have recognized the immense value of satellite and aerial Remote Sensing (RS) and obtained a perspective from space that allows them to better understand archaeological known and unknown landscapes and their wider contexts [6]. Compared with passive RS (photography and multi-/hyperspectral), active RS (radar and lidar) has the advantage of being able to detect buried desert sites [7] or to detect hidden archaeological landscapes in forest environment [8].

The possibility to discriminate features related to surface of subsurface sites is related to the changes and alteration of the ground. The ground indicators are categorized as follows [9]:

- Vegetation and soil moisture marks
- Surface alteration and micro-relief marks
- Continuity marks

Vegetation marks are due to visible changes in the vegetation growth status or health detectable as different vegetation colours, while soil moisture marks are due to alteration of the moisture/water content of the soil for a "positive feature" such as a hidden wall or a "negative feature" such as a ditch generating in a different surface color (Figure 2).

Fig. 2. Vegetation and soil moisture anomalies.

Surface alteration marks are due to artificial or natural events that altered the characteristics of the soil surface (e.g., ploughing, fire, intense rain etc.). Micro-relief marks, on the other hand, are due to the sun inclination effect, visible only in a specific time frame where the shadows caused by the sunlight enhance the presence of an elevation pattern standing out from its surroundings (Figure 3).

Fig. 3. Surface alteration and micro-relief marks.

Continuity marks are related to the persistent usage of ancient settlements under a topographic point of view, a typical example is provided by the case of Piazza Navona in Rome, which stands on the ancient Domitian Stadium, commissioned around AD 80 by the Emperor Titus Flavius Domitianus (Figure 4).

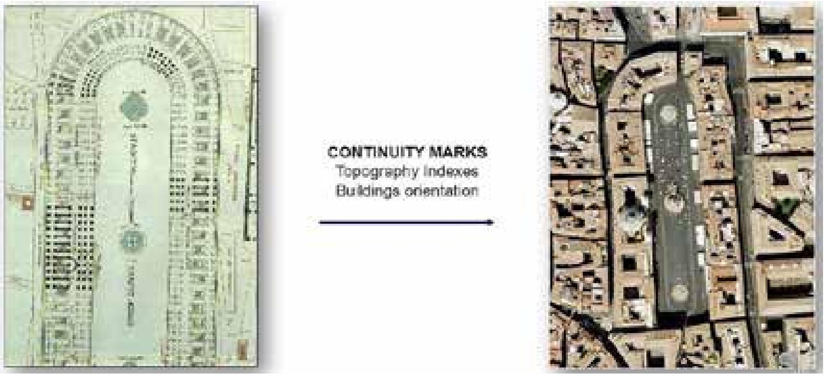


Fig. 4. Topography and continuity marks.

All these ground anomalies and related indicators are affected by seasonality changes. For this reason, and for a deep and accurate feature extraction evaluation, a multi-temporal analysis is needed.

Nowadays, we dispose a large set of data processing and analysis techniques for land monitoring and applications, where also the monitoring of Cultural Heritage can be included. The possibile techniques that can be used in the field are, to cite a few, Image enhancement, classification, spectral indexes, Change detection, feature extraction, SAR Image Speckle Filtering, SAR Image segmentation, SAR Interferometry (InSAR, Figure 5) and Polarimetry, and many others.

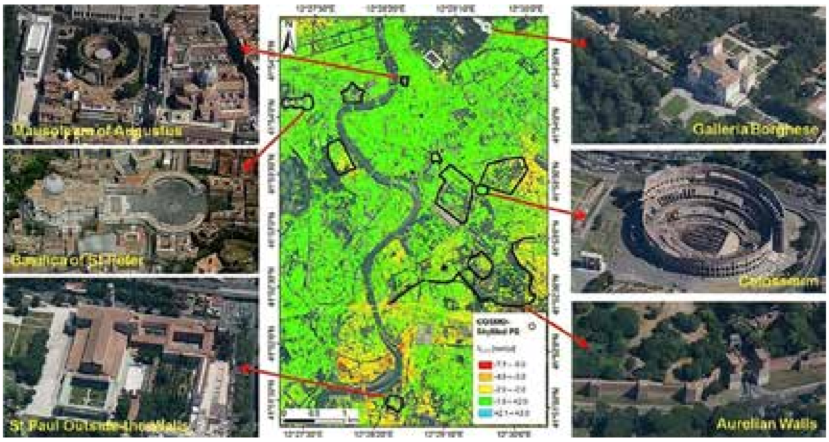


Fig. 5. InSAR measurements for ground displacement in the center of Rome, Italy @PROTHEGO project.

However, challenges and recommendations need to be considered and, in particular, those related to the atmospheric conditions affecting data quality, such as clouds and haze, as well as limitations in spatial and spectral resolution that can impact the ability to detect and distinguish small or subtle features. Also, weather conditions may restrict data acquisition or introduce distortions in the captured imagery. Sensor calibration, geometric distortions, and radiometric corrections are other parameters to be taken into account. New technologies in the filed of EO applications such as Artificial Intelligence are starting to widen the range of opportunities especially in terms of data analysis and features extraction, change detection and monitoring, classification and object recognition, data fusion and integration.

Remote sensing plays a crucial role in observing and understanding cultural landscapes by providing a comprehensive and synoptic view of the Earth's surface. It allows us to capture and analyze the spatial and temporal changes in cultural features, such as archaeological sites, heritage structures, and historical landscapes.

However, the interpretation of remote sensing data can be challenging due to inherent uncertainties and the need for expertise in data analysis and interpretation. Ground truth, which involves collecting and validating on-site data, is necessary to verify remote sensing interpretations and establish accurate relationships between the observed data and real-world features. Integrating ground truth data with remote sensing analysis enhances the reliability and credibility of the results and plays a fundamental role in reaching a reliable analysis.

3. Case studies and applications

We need to consider three key concepts when talking about Cultural Heritage from Space:

- Understand: we need to identify the status and the possible risk factors affecting the cultural landscape (Subsidence, ground motion detection, Urban sprawl monitoring, Climate Change indicators, Sites monitoring and detection (buried sites)
- Secure: we need to identify actions and procedures to face natural and artificial threats (Monitoring of the destruction or looting of sites, Air pollution monitoring, Coastline monitoring (erosion)
- Benefit: we need to understand how our actions can support and improve the preservation of cultural heritage (Risk assessment/Land use change maps, Preventive investigation for infrastructures realization, Dissemination of culture awareness).

In the frame of the 4th edition of this international summer School, examples of applications related to these three concepts have been presented and are summarized in the following sections.

4. Understand: Sites monitoring and detection

In figure 6, the example of data integration in a GIS environment is shown. The amount of information provided by different data sources, and simultaneously visualized, constitutes the great potential of a dynamic container that can be consulted at different levels. The possibility of observing an overall view of an archaeological site, as well as details linked to specific aspects, facilitates the communication between archaeology and technology. This is truer especially when a 3D structures extrusion of ancient structures is added to the already remarkable amount of available information.

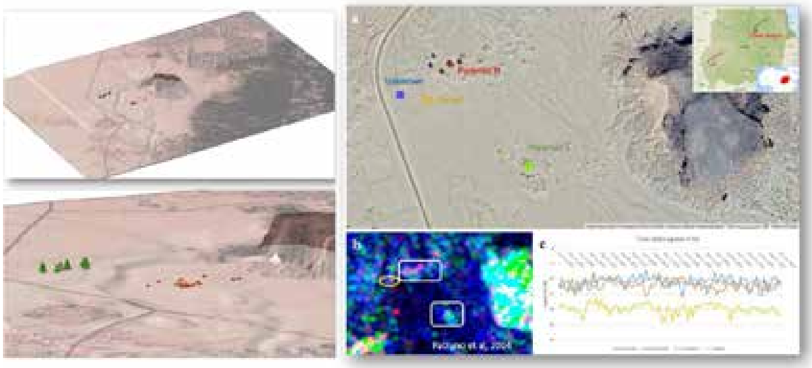


Fig. 6. Features extrusion and optical data superimposition in the GIS environment. Analysis of the SAR time-series backscattering over known and unknown features. @Patruno et al, 2019.

The digitalisation can provide an immediate idea of the overall environment and of structure's interaction with it. The data integration in the GIS environment creates a useful bridge between a very well-known source of information as EO optical images and a more complex data (SAR) and their relationship with a wide set of ancillary data. Thanks to this multi-disciplinarity, the relationships between noticed anomalies and archaeological structures becomes more understandable also for non-experts and emphasizes the communicative potential of such a interdisciplinary approach.

5. Secure: Destruction of sites and risk assessments

In not accessible cultural landscapes, Remote Sensing is the only source of site monitoring. Following the IS attack in 2015, UNITAR/UNOSAT realized a series of analysis highlighting the loss of archaeological buildings in the Middle East area. One of those occurred at Nimrud Citadel, about 32km south of Mosul and founded more than 3,300 years ago (Figure 7).

One of the objectives of cultural heritage monitoring is also to privilege preventive actions to reactive ones, especially when facing extreme weather conditions and climate change. In figure 8, examples of major threats in terms of climate change effects are illustrated. Thunderstorms, wildfires, coastal erosion and sea level rise and heavy rains are more and more affecting the worldwide cultural heritage (Figure 8).

Fig. 7. Analysis of ancient buildings loss after terroristic attacks in Iraq, @UNITAR/UNOSAT 2015

Fig. 8. Extreme weather events on cultural heritage sites.

6. Benefit: Risk assessment, prevention plans

The methods of investigation on CH, and in particular in the archaeological field, are multiple and, if applied individually, rarely allow us to obtain exhaustive information for the historical reconstruction of ancient contexts. They consist of techniques that involve different approaches to CH and can be divided into two broad categories:

- invasive analysis (such as archaeological excavation that compromises the integrity of the site but obtains large amounts of detailed information);
- non-invasive analysis (such as landscape archaeology studies) carried out at a macro-scale level (aero photo interpretation derived by drones' acquisitions or by historical images, or archaeological surveys that allow to identify archaeological areas of interest on the ground) and for limited areas (ground prospections methodologies such as GPR, magnetometry etc.).

Earth Observation falls into this second category and can constitute (the conditional is a must, given the potential for technical improvement of this discipline) a tool of research that should increasingly fall into the list of usual archaeological investigation techniques. In this context, the Copernicus services [10], drawing from satellite EO and in-situ (non-space) data, provide today open and free value-added data to users and are constituted by a set of six specific services: Land, Security, Emergency, Climate Change, Marine, Atmosphere (Figure 9). As a matter of fact, most of those services can also contribute to the monitoring and preservation of cultural landscapes and sites. Copernicus is the European system for monitoring the Earth and is coordinated and managed by the EC (European Commission). The development of the observation infrastructure is performed under the aegis of ESA (European Space Agency) for the space component and by the EEA (European Environment Agency) and EU (European Union) countries for the in-situ component.

Fig. 8. Copernicus Services.

7. Conclusion and recommendations for a way forward

Aerial photography and photointerpretation knowledge have deeply influenced archaeological research and became the principal scientific investigation tools and then converging as the analysis of very high spatial resolution optical satellite images. The use of SAR satellite data for archaeological investigations has been explored more and more in recent years, despite some initial limitations:

- General complexity of data analysis and interpretation
- Need of a specific technical knowledge for archaeologists
- Inexistence of an automatic procedure designated to the recognition and extraction of archaeological features
- Lack of visual communication between the well-known aerial photographs or optical data and SAR satellite data.

The contribution of EO services and products such as those from Copernicus and ESA Contributing Missions in last years for Cultural Heritage has proven their usefulness for the management of cultural heritage during emergencies (especially in the case of geo-hazards) and for the mapping, monitoring and preservation of cultural heritage as a daily routine.

However, it is still recommended to:

- Strengthen the communication and the synergies between EO experts and Cultural Heritage management
- Provide user-ready products (connection between the data providers and the end-users - site managers)
- Supporting the generation of processes and practices for technology and Cultural Heritage

With these premises, the integration of multi-source data in land application analysis enhances the accuracy and effectiveness of the analysis by combining the strengths of different remote sensing techniques and datasets. By integrating optical, SAR, LiDAR, and other data sources, we can obtain a more complete and detailed understanding of cultural landscapes, enabling better identification, mapping, and monitoring of cultural heritage sites and their surrounding environments. This integrated approach enables a holistic assessment of cultural landscapes and supports informed decision-making for conservation, management, and sustainable development of our cultural heritage, and the GIS environment still constitute a precious single point access information.

Bibliography

1. Ciski, M.; Krzysztof R. «Threats to Cultural Heritage Caused by the Global Sea Level Rise as a Result of the Global Warming». Water, vol. 13, fasc. 18, settembre 2021, p. 2577. DOI.org (Crossref), https://doi.org/10.3390/w13182577.
2. Moise, C. et al. «Remote Sensing for Cultural Heritage Assessment and Monitoring: The Case Study of Alba Iulia». Sustainability, vol. 13, fasc. 3, gennaio 2021, p. 1406. DOI.org (Crossref), https://doi.org/10.3390/su13031406 .
3. Crawford O.G.S., 1923, *"Air Survey and Archaeology"*, The Geographical Journal.
4. Doneus M., Briese C., Fera M., Janner M., 2008, *"Archaeological prospection of forested areas using full-waveform airborne laser scanning"*, Journal of Archaeological Science.
5. Lasaponara R., Coluzzi R., Masini N., 2011, *"Flights into the past: Full-Waveform airborne laser scanning data for archaeological investigation"*, Journal of Archaeological Science.
6. Luo et al., 2019, *"Airborne and spaceborne remote sensing for archaeological and Cultural Heritage applications: A review of the century (1907-2017)"*, Remote Sensing of the Environment.
7. Patruno, J., Fitrzyk M., Delgado Blasco, J.M., 2020, *"Monitoring and Detecting Archaeological Features with Multi-Frequency Polarimetric Analysis"*, Remote Sens. 2020, 12(1), 1; https://doi.org/10.3390/rs12010001.
8. Prumers, H., Betancourt, C.J., Iriarte J., Robinson, M., Schaich, M.,

   2022, *"Lidar reveals pre-Hispanic low-density urbanism in the Bolivian Amazon"*, Nature.
9. Ceraudo, G., Piccarreta F., Wilson Myers J., 2002, *"Manuale di aerofotografia archeologica: Metodologia, tecniche, e applicazioni"*, American Journal of Archaeology, DOI: 10.2307/4126293
10. https://www.copernicus.eu/en/copernicus-services

MODULE III

HISTORIC BUILDING INFORMATION MODELLING (HBIM)

Management of the maintenance cycles of historic buildings and the opportunities of the Digital Building Logbook

Flavio Rosa

CITERA, Interdepartmental Centre for Territory, Building, Conservation and Environment, Sapienza University of Rome, Italy

flavio.rosa@uniroma1.it

ABSTRACT

Historical buildings possess architectural and cultural significance, requiring careful preservation and adaptive reuse while accommodating modern technological systems.

The integration of Historic Building Information Modeling (HBIM) with Mechanical, Electrical, and Plumbing (MEP) systems and other technological components offers a comprehensive solution for managing and optimising the performance of these buildings, as described in this work.

The building industry's digitalization can aid in the design of interventions using Digital Twin DT techniques, which can then be combined into a single document known as the Digital Building Logbook (DBL). We put forth a description of an innovative workflow that characterises technology advancements and integrations within the portfolio of historical buildings. This work offers practical ideas to enhance the efforts of designers and companies in reducing seismic vulnerability during maintenance or energy retrofitting. These suggestions aim to ensure and enhance the protection and preservation of Italy's historical building stock.

INTRODUCTION

In light of the novel technologies and the energy transition, this study seeks to begin an investigation of the prospects that the construction industry's digitization and computer processing can offer for the preservation [1], improvement [2], and security of the historical building stock. A theme [3] with numerous applications to energy retrofitting and maintenance and management. Two perspectives are used to present the historicity found in the building stock of Italy, and particularly in Rome: the first is that of protection and safeguarding in accordance with current Italian legislation [4], and the second is that of the building process as a technical project that is realised by all the players in the construction sector [5].

This paper mainly focuses on the second analysis and evaluates some important aspects of traditional historical architectural stock. This ignores the load-bearing masonry structure, which is only protected by the perimeter components of the building [6]. As per Mazzarella and Webb [7,8], historic buildings can be categorized into two main types: historical buildings (HB) and traditional buildings (TB). They possess three defining attributes: age, integrity, and significance. these structures have typically stood for at least 50 years and are often recognized as listed features.

Traditional buildings TB differ only in one feature: their shell structure. This latter classification is too vague and difficult to interpret, and has significant implications for "traditional" structures [9].

Most of the Italian heritage building stock does not present stringent protection restrictions as required by current regulations [10]. A third proposed classification, Traditional Historical Buildings (THB), encompasses structures not explicitly covered under the maintenance and restoration guidelines of the Code of Cultural and Landscape Heritage. Here, the historical significance of the building is assessed within the context of the specific Italian post-unification period (1871–1942), with urban design, building types, construction techniques, and material technology not designated as having particular interest or value for ensuring their preservation as outlined in Cultural Heritage codes.

This building stock is subject to periodic maintenance cycles which often impact their load-bearing structures in an irreversible way. A particular declination of the concept of protection, for the THBs which are very numerous in Rome, is presented in this work. In figure 1 the distribution of load-bearing masonry buildings in Rome is highlighted.

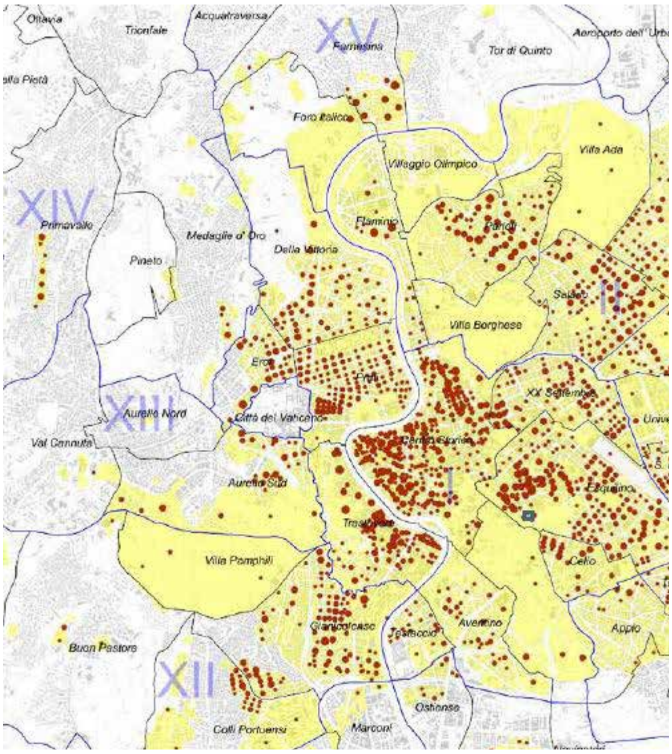


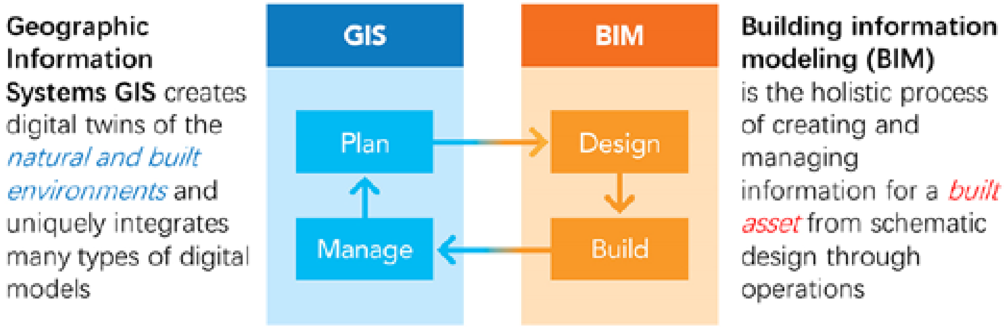
Figure 1 Map of load-bearing masonry buildings in Rome

Historic buildings are irreplaceable treasures that provide a link to our past, cultural heritage, and architectural legacy. Preserving and maintaining these buildings pose unique challenges due to their historical significance, aging infrastructure, and the need for accurate documentation. DT technology, coupled with (GIS) and BIM applications, presents novel opportunities to overcome these challenges and advance the conservation and management of historic buildings.

Michael Grieves is an academic and researcher who coined the term "DT" in the early 2000s and made significant contributions to its development. Defines a DT as a virtual representation of a physical product, process, or system.

Digital Twin present a transformative approach to the preservation and maintenance of historic buildings, combining advanced technologies with traditional conservation practices.

A Geographic Information System (GIS)-based digital technology (DT) integrates spatial data, including satellite imagery, aerial photography, topographic maps, and sensor data to create a comprehensive representation of the physical environment. In the context of GIS, a DT refers to a virtual representation or digital replica of a physical geographic area or object. It combines geospatial data, analytical capabilities, and simulation techniques to create a dynamic and interactive model that mirrors the real-world geographical features, properties, and behaviours. Figure 2 below summarizes existing studies about BIM, its application in the heritage sectors, FM and restoration planning, and their integration [11].



Geographic Information Systems GIS creates digital twins of the *natural and built environments* and uniquely integrates many types of digital models

Building information modeling (BIM) is the holistic process of creating and managing information for a *built asset* from schematic design through operations

Figure 2 An approach to the integration of GIS and BIM

Leveraging open standards, BIM has been utilized for 3D parametric modeling, project planning, and lifecycle management. The adoption of BIM is widely recognized as advantageous for both the design and maintenance phases of new buildings. Furthermore, its application in heritage building is widely adopted to scan the as-built heritage assets using photogrammetry techniques and the conversion of the heritage scan model into a parametric 3D digital model with attached documents. However, there is a research gap in BIM application for the restoration planning and Facility Management (FM) of heritage buildings; also, the existing studies lack defined information needed for the maintenance and management of heritage buildings. The implementation of maintenance works, such as preventive maintenance and corrective maintenance, for heritage building sis rarely discussed. Figure 3 shows a graph that summarizes the interactions between BIM, Heritage buildings, Restoration activities, FM with methodologies and tools analyzed by M.S. Khan et al.

Figure 3 summarizes existing studies about BIM, its application in the heritage sectors, FM and restoration planning, and their integration [11].

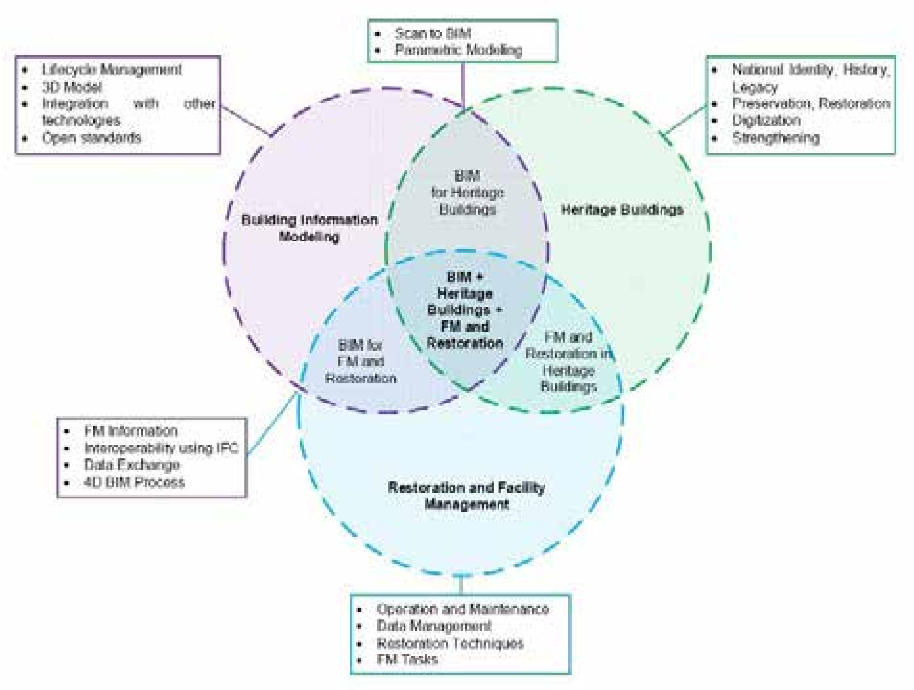


Figure 3 existing studies about BIM, its application in the heritage sectors (Source [11]).

Using open standards, BIM has been applied for 3D parametric modeling, project planning, and lifecycle management. The implementation of BIM is highly acknowledged to be beneficial for the design and maintenance of new buildings.

Protection and conservation of the modern and contemporary building stock with digital solutions

The convergence of DT technology and Historical Building Information Modeling (HBIM) has significantly transformed the landscape of the Architecture, Engineering, and Construction (AEC) industry. This paper explores the integration of DT and HBIM methodologies in the context of building lifecycle management, with a focus on the utilization of the Digital Building Logbook (DBL). The DBL serves as a comprehensive repository of digital information, facilitating efficient documentation, collaboration, and decision-making throughout the entire building lifecycle.

Building Logbooks are repositories for detailed building information. They act as a single point of input, access and visualization of all the information associated with a building unit throughout its lifecycle [12]

Figure 4 DBL according to the definition of the BPIE

DT technology involves the creation of a virtual replica of a physical asset, providing real-time data and insights. HBIM, on the other hand, focuses on preserving the historical information of a building throughout its existence. The integration of these two approaches results in a powerful framework that combines the benefits of real-time monitoring and historical preservation.

The DBL emerges as a central component in this integrated approach. It acts as a dynamic repository, housing a wealth of information related to the building's design, construction, and operation. The logbook is continuously updated with real-time data from sensors, maintenance records, and other relevant sources, ensuring a comprehensive and up-to-date digital representation of the building.

Benefits of DBL:

- Efficient Lifecycle Documentation: The Digital Building Logbook streamlines the documentation process throughout the building lifecycle. This includes design and construction data, maintenance records, energy consumption patterns, and other critical information.
- Collaborative Decision-Making: The logbook facilitates collaboration among stakeholders by providing a centralized platform for information sharing. This promotes informed decision-making at various stages, from design modifications to maintenance planning.
- Predictive Maintenance: Leveraging real-time data from sensors and historical information, the Digital Building Logbook supports predictive maintenance strategies. This helps in proactively addressing potential issues, minimizing downtime, and optimizing operational efficiency.

The DT strategy and the creation of a design workflow with HBIM tools can be integrated into the DBL. This integration of innovative procedures and tools represents a great opportunity for the protection and safety of all the historical Italian building stock.

- Historical urban planning framework of the intervention;
- Research and analysis of project documentation as well as all previous interventions and works;
- On-site surveys, photographic, geometric, and non-destructive surveys in a DT modelling perspective;
- Recognize the architectural and mechanical language of masonry construction;
- Provide a fast building quality index (IQM) of the housing unit contextualized to the entire building
- Avoid mechanical, physical, and chemical incompatibilities;
- Aim for a minimum of intervention, including safety and conservation;

- Evaluate the interaction of the building under consideration within the building aggregate, if any.
- Planning of destructive investigations commensurate with project interventions
- Impact assessment and possible design solutions (mitigations) of interventions on load-bearing masonry structures
- Production of complete reports certifying the solutions adopted to be integrated into the digital booklet of the building in DT optics and the function of the DBL.

Intervention in an existing building requires reasoning about the inadequacy of traditional design methods and tools [13]. The comparison with the complexity and multidisciplinary nature of the existing project inevitably involves the experimentation of new processes and new technologies able to prefigure and verify the effectiveness of the transformations.

Vulnerabilities of the historical building stock: innovative approaches and solutions

For each category of intervention authorised by the Consolidated Law on Construction, we emphasise a new notion of vulnerability for THB that considers the potential modifications to the load-bearing masonry structures.

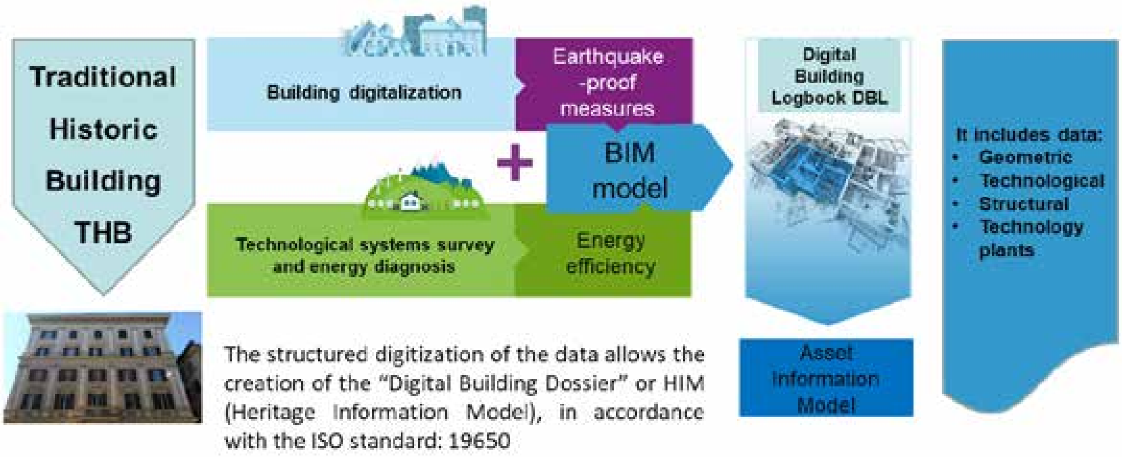
The technical designer must be able to assess the kind and mode of energy retrofitting interventions on existing buildings, including THB masonry bearing, using his expertise, experience, and level of confidence. An analysis approach that spans the phases of design and implementation must be derived from the degree of confidence. The designer or site manager will evaluate if the works have no effect on the structures as part of this process.

Studies examining the evolution of residential buildings about seismic hazards have focused on the susceptibility of masonry buildings in the Roman area. In their research on the susceptibility and risk of damage to buildings, Colozza and Dolce [14] deem an ad hoc methodology necessary for evaluating the condition of the supporting structures. This methodology calls for a prioritised historical analysis of the Roman building to define the structural characteristics associated with the processes of birth, development, and transformation.

As a result, a different, though not necessarily higher, degree of uncertainty typically affects the safety assessment and the design of the interventions.

Energy retrofitting projects, particularly on THB, must always be completed with a method that considers structural issues, beginning with a single housing unit and extending to the entire structure in light of prior maintenance.

The figure below proposes the data and information flow scheme for the integration of different THB information datasets into a DBL logic.



The structured digitization of the data allows the creation of the "Digital Building Dossier" or HIM (Heritage Information Model), in accordance with the ISO standard: 19650

Figure 5 Proposal for the integration of different THB information datasets into a DBL logic.

The digital management of the entire information cycle of the building through a DBL logic allows for systematic and up-to-date information over time and space as shown in the figure below.

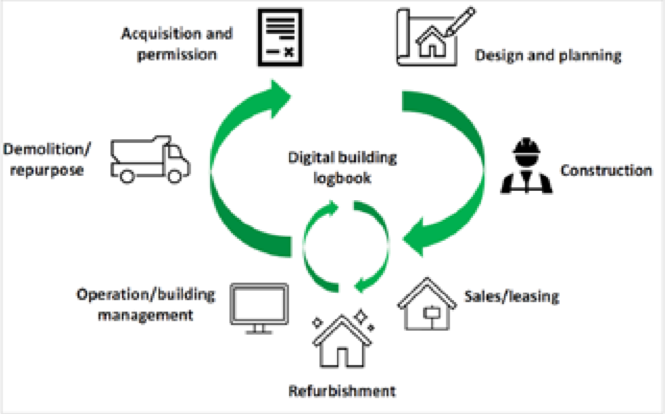


Figure 6 (Source: Report 1 of the Study on the Development of a European Union Framework for Buildings' Digital Logbook)

Proposed innovative workflow for the maintenance cycles and retrofit intervention on the Traditional Historic Building

This study is the initial phase of formulating a novel strategy utilizing DT modelling technologies targeted at DBL for a restructuring of the full building process maintenance of THB including all stakeholders: contractors, public administrators, and technicians.

Using a cross-cutting approach, the study was conducted on three macro-areas: seismic vulnerability, energy retrofitting cycles (ERC), and THB. This allowed us to create a novel workflow unique to the THB category. As a result, DT and DBL's expertise and processes are integrated, enabling the creation of a strategic plan for the upkeep, security, and protection of the historical building stock—particularly the THB, which requires specific methods and solutions.

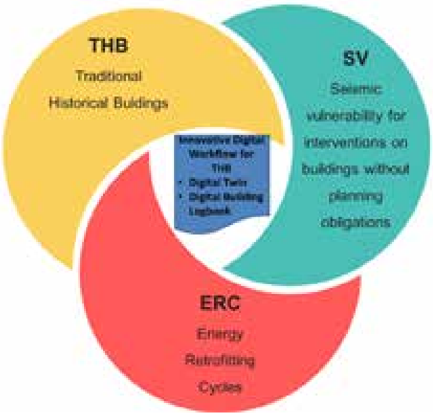


Figure 7 Proposed innovative workflow for the maintenance cycles and retrofit intervention on the THB [15]

The analysis was carried out on the three macro-areas: Traditional Historical Buildings (THB), Seismic Vulnerability (SV) and Energy Retrofitting Cycles (ERC) through a cross-cutting approach that allowed us to define an innovative workflow specific to the category of THB. The result is an integration of knowledge and procedures between DT and DBL that allows the definition of a strategic document for the maintenance, protection, and security of the historical building stock, and of the THB that needs specific approaches and solutions.

Conclusion

The integration of DT and HBIM, with a focus on the Digital Building Logbook, represents a transformative approach to building lifecycle management. This paper highlights the benefits of this integration, presents case studies to validate its practical applications, and discusses challenges and future directions. The Digital Building Logbook emerges as a key enabler for efficient documentation, collaboration, and decision-making throughout the building lifecycle, paving the way for a smarter and more sustainable built environment.

[1] L. De Santoli, F. Mancini, C. Clemente, S. Lucci, Energy and technological refurbishment of the School of Architecture Valle Giulia, Rome, Energy Procedia. 133 (2017) 382–391. doi:10.1016/J.EGYPRO.2017.09.366.

[2] G. Lo Basso, F. Rosa, D. Astiaso Garcia, F. Cumo, Hybrid systems adoption for lowering historic buildings PFEC (primary fossil energy consumption) - A comparative energy analysis, Renew. Energy. 117 (2018) 414–433. doi:10.1016/j.renene.2017.10.099.

[3] D. Astiaso Garcia, U. Di Matteo, F. Cumo, Selecting eco-friendly thermal systems for the “Vittoriale Degli Italiani” historic museum building, Sustainability. 7 (2015) 12615–12633. doi:10.3390/su70912615.

[4] F. Mancini, S. Romano, G. Lo Basso, J. Cimaglia, L. De Santoli, How the Italian Residential Sector Could Contribute to Load Flexibility in Demand Response Activities: A Methodology for Residential Clustering and Developing a Flexibility Strategy, Energies 2020, Vol. 13, Page 3359. 13 (2020) 3359. doi:10.3390/EN13133359.

[5] M. Manfren, B. Nastasi, L. Tronchin, D. Groppi, D.A. Garcia, Techno-economic analysis and energy modelling as a key enablers for smart energy services and technologies in buildings, Renew. Sustain. Energy Rev. 150 (2021) 111490. doi:10.1016/J.RSER.2021.111490.

[6] F. Rosa, E. Carbonara, An analysis on technological plant retrofitting on the masonry behaviour structures of 19th century Traditional Historical Buildings (THB) in Rome, Energy Procedia. 133 (2017) 121–134. doi:10.1016/j.egypro.2017.09.378.

[7] L. Mazzarella, Energy retrofit of historic and existing buildings. the legislative and regulatory point of view, Energy Build. 95 (2015) 23–31. doi:10.1016/j.enbuild.2014.10.073.

[8] A.L. Webb, Energy retrofits in historic and traditional buildings: A review of problems and methods, Renew. Sustain. Energy Rev. 77 (2017) 748–759. doi:10.1016/j.rser.2017.01.145.

[9] F. Rosa, M. Tiberi, Introduzione alla riqualificazione energetica ed ambientale degli edifici storici : il caso di Roma, Sci. e Tec. 511–512 (2013) 1–7.

[10] MIBACT Ministero per i beni e le attività culturali, Legislative Decree n. 42 of 22 January 2004. Code of cultural and landscape heritage., (2004). http://www.unesco.org/culture/natlaws/media/pdf/italy/it_cult_landscapeheritge2004_engtof.pdf (accessed March 23, 2017).

[11] M.S. Khan, M. Khan, M. Bughio, B.D. Talpur, I.S. Kim, J. Seo, An Integrated HBIM Framework for the Management of Heritage Buildings, Build. 2022, Vol. 12, Page 964. 12 (2022) 964. doi:10.3390/BUILDINGS12070964.

[12] Digital Building Logbooks Archives > BPIE - Buildings Performance Institute Europe, (n.d.). https://www.bpie.eu/keyword/digital-building-logbook/ (accessed December 16, 2023).

[13] S.F. Mousavi Motlagh, A. Sohani, M.D. Saghafi, H. Sayyaadi, B. Nastasi, The Road to Developing Economically Feasible Plans for Green, Comfortable and Energy Efficient Buildings, Energies 2021, Vol. 14, Page 636. 14 (2021) 636. doi:10.3390/EN14030636.

[14] M. Dolce, R. Colozza, Vulnerabilità e rischio di danneggiamento degli edifici. in "La geologia di Roma - ilcentro storcio" coordinamento scientifico Renato Funiciello, Roma, ROMA, 1985. http://www.isprambiente.gov.it/it/pubblicazioni/periodici-tecnici/memorie-descrittive-della-carta-geologica-ditalia/memdes_50_8_3.pdf (accessed May 2, 2017).

[15] F. Rosa, Digital Twin solutions to historical building stock maintenance cycles, IOP Conf. Ser. Earth Environ. Sci. 1073 (2022) 012013. doi:10.1088/1755-1315/1073/1/012013.

HBIM Application in Guangxi

Sisi Tan, Lin Zhou, Shaokun Liu, Yating Liu, Zhen Yue

Lecturer in the school of Architecture Engineering, Liuzhou City Vocational College, Liuzhou, Guangxi, PR China.

271613557@qq.com

Abstract

This paper introduces the development, repair and maintenance of wooden structure buildings by describing the features of topography and geomorphology, customs and cultural traditions in the south. Through the repair and maintenance work of several wooden construction cases, the specific application ways and methods of HBIM in Guangxi are discussed.

Keywords: wooden structure, HBIM, Restoration

1. Introduction

China is in the second half stage of urbanization development, and a large number of urban buildings have appeared in some traditional villages, and the concept of heritage protection is not recognized by most villagers. The characteristics of traditional villages are not just physical objects in surface appearance or experience, but a way of cultural imagination or image representation, deconstruction and symbol of the environment. In order to continue the village features and cultural connotations with vigor, it is necessary to find appropriate ways for the development of specific traditional villages according to local conditions, organically combine the inner civilization of villages, combine development and protection, and highlight local traditional characteristics to make proper use of their own resources for village development and construction.However, these ideas are in contradiction with the needs of village development in the minds of villagers, making it impossible to carry out the village development and protection planning in depth. The content of the work is often one-sided, focusing on material appearance, lacking the understanding of traditional village civilization, and the work of continuing the value of historical civilization is out of the question [1].

Dong architecture originated from ancient ganlan-style architecture, where houses were built on rugged mountains. After the Ming Dynasty, the mature wooden building construction skills in the Central Plains were introduced into the Dong area, and the architectural structure became complicated, and finally formed the architectural form dominated by the tenon through building structure. The building is composed of a framed bent, which is connected by a rod through each landing column , and the framed bent is connected through the square. The more the framed bent, the larger the area and volume of the house. Add a piece of structure to the top and you have a building. All parts are tenon and mortise joint, without the need for iron nails and adhesive. Dong wooden architecture is not only beautiful in shape, but also unique in craft. The whole building including the beam column beam connect without any steels. The cultural connotation around wooden buildings is rich and the artistic value is high. Dong craftsmen follow the rules of balance, symmetry and harmony in the design of wooden structure buildings, and pay attention to the multiple combinations of straight lines, oblique lines, curves and broken lines, which constitute the architectural plastic art of harmonious proportion, balanced symmetry and perfect rules in beauty. In the Dong wooden architecture, the architect does not need to manuscripts or make models, the overall idea is all in the mind, only with the self-made small Angle ruler, with a bamboo ruler and a bamboo blade clean ink pen, and etc.to sketch hundreds of beams, columns and other components of different lengths and sizes.

Most of the Dong buildings are wooden structures, and many of the ancient buildings are very old, no one has repaired them, and they are facing the situation of imminent disappearance. Restricted by the specific mountain conditions in the Dong area, the overall living standard of the Dong people is still very low, and the economic development is also unbalanced, which seriously affects the protection and development of the Dong cultural heritage.

Fig. 1. Dilapidated Dong wooden buildings.

2. Methods-Case study

2.1. Restoration of residential building for Huang major general

Located in Liucheng village, this building is the official residence of Major General Huang in the early period of the Republic of China, and is now a local key cultural relic. However, due to some historical reasons and the residents' previous weak awareness of protection, the building not only fell into disrepair, but also by destroyed by some people. These residents demolished some cultural facilities within the area and built new houses after obtaining the approval of the local government.

In the upper left picture, the beam has a slight splitting deformation, but it does not affect its load-bearing performance. In the upper right picture, it can be seen that the wall is cracked due to long-term rain erosion, and part of the brick in the wall is missing. In the lower picture, it can be seen that the tile that initially shielded the roof is also partially missing.

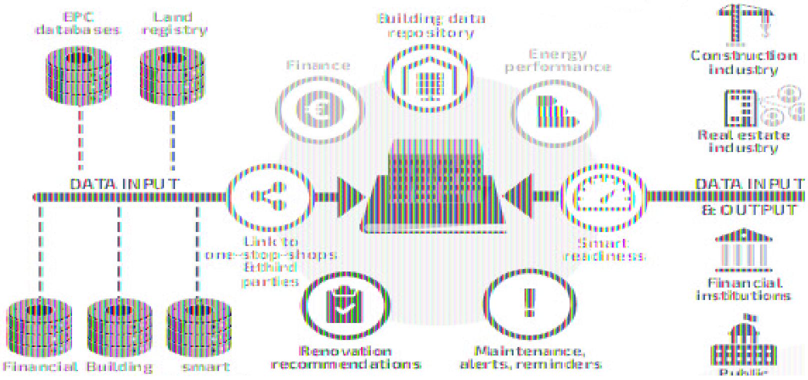


Fig. 2. Dilapidated walls and roof of Huang major general building.

After field investigation and observation, we use UAV aerial survey to detect the three-dimensional model, and focus on the roof part to detect whether the bearing part of the structure is damaged, whether it affects the force, and carry out one-to-one restoration of the missing tiles under the condition of ensuring integrity. For the broken beams, after the structural support maintenance, find the original tree to replace the broken beams. The defects of the wall are filled with black bricks, and the original missing doorway is reproduced according to historical records.

2.2. He's ancestral hall

He Ancestral Hall is located in Liucheng village, Liuzhou City. It is a building moved from Guangdong He family in Qianlong period of Qing Dynasty. According to the field measurement, the ancestral hall is located in the middle of the residential area, about 43 meters long and 33.8 meters wide, with a total construction area of 1386 square meters, the highest building is about 6 meters high, and other buildings are about 5 meters high. The whole ancestral hall is symmetrical between the central axis when the heart, and the ancestral hall is composed of the front hall, the middle hall and the back hall.

The ancestral hall was originally a pure wooden structure. Later, due to the frequent wet and rainy weather in the local area, many wooden structures deteriorated. In 2002, the original wooden wall structure was replaced by brick walls. Now, after more than ten years, the original masonry wall has been partially collapsed by others, the wall skin has also been seriously shed, the spray paint on the column and the board has also begun to fall off, and the column has a few cracks, but the roof truss structure is still complete. There are many missing doors and Windows in the entire He family ancestral hall.

Fig. 3. Missing roof and walls of He ancestral hall.

After investigating, the damaged wooden columns were replaced with columns of the same material and size by using local materials. The missing doors and Windows were customized by a specialized factory according to the existing architectural style, and then installed. The wall and column need to find a professional antique building restoration company, investigate and study the color of the original paint and raw materials therefore it can be 1:1 reduction, and carry out anti-corrosion and waterproof treatment for the whole house. The part of the brick wall is also re-adjusted and base on finite element mechanical analysis to carried out to design more reasonable brick size and brick wall masonry form for re-construction. The original building patio was retained to allow for light.

2.3. Town Planning with Restoration Application

The historical buildings in town are old, and the surrounding public spaces are lacking in design, which leads to the slight spread of the architectural groups in town, and also causes a lot of waste. Therefore, the design aims to use modern architectural techniques and structural nodes to add wooden glass windows, antique wooden doors and glass curtain walls without changing the materials and elements of the traditional dwelling of Mulao people to make the tradition and modernity integrated.

The survey found that the villagers lack centralized public places, and the awareness of cultural heritage protection is weak, so the villagers' activity center and academy are planned, which not only bring recreation places for the villagers, but also provide learning places for the villagers to improve their awareness of cultural heritage inheritance and promote the Mulam ethnic culture. In order to increase the income level of the villagers, additional characteristic Spaces such as commercial streets, characteristic processing workshops and cultural corridors are established, which can not only bring economic benefits to the villagers, but also provide opportunities for the development and inheritance of Mulam ethnic culture.

The Village Centre and College are located on the newly built road in the center of Tai Lee Tun to serve as a gathering point for residents and complete the activities in the Tun, which is close to the village committee and the park. The two buildings stand side by side with a pastoral view behind them. The two buildings are mainly brick and wood structures, the roof adopts a streamlined design, and the glass curtain wall is mainly used to increase the amount of light in the building. In front of the entrance of the village center, there is a small square with stone slabs, allowing the building to blend with the natural environment.

Fig.4. Country diagram of ethnic village.

The roof design borrows from the Phoenix feather, which is a totem of ethnic minorities, therefore the use of irregular roof will reserve more architectural space for the building itself. The platform on the second floor and the lift space on the first floor can form a spatial interaction between the two floors, and the large area of floor-to-ceiling Windows provide visitors with a position to enjoy the landscape. The opening of the entrance hall on the first floor enriches the space with light and shadow effects. The atrium of the building can solve the problem of less lighting and play a role in beautifying the space.

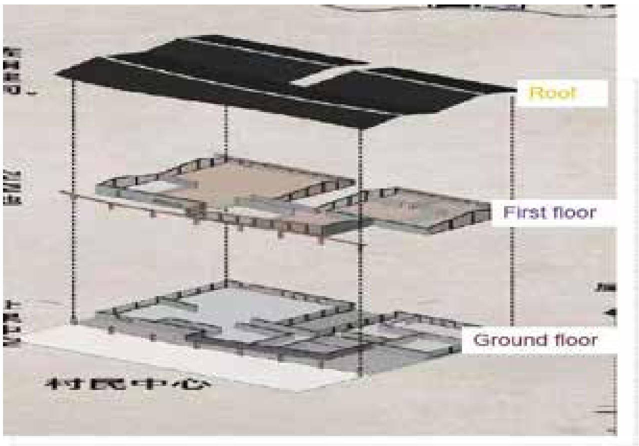


Fig.5. Structure of village center.

2.4. Methodology of data collection

All the restoration for wooden buildings are based on digital documents. There are three steps for digital documents collection. First step is data collection: Basic data is a necessary condition for the construction of digital documents, and all models and other derivative materials in the later stage need to use the actual data collected in the earlier stage. Data collection includes investigation of individual documents, collection of historical pictures, current video images, scanning and mapping, etc. Second step is data processing: In this stage, it is mainly responsible for the processing to generate higher value with secondary development of the collected data. For the conservation work of historical bridge, accurate and intuitive dimensional data of each component and similar component family storeroom can play a great role in the later repair or restoration work. The results of data improvement include structural plan, 3D BIM model, UAV panoramic image model, 3D point cloud model, simulation animation, ancient bridge component family storeroom, etc. Final step is structured data: Based on the data generated by data collection and processing, the digital information of each ancient bridge will be classified and archived, and a systematic ancient bridge database will be provided for the reader through human-computer interaction mode, and a comprehensive digital archive resource will be provided for the further development and research of the digital twin of ancient Bridges in the future. The data consolidation content is divided into first-level review, second-level review and third-level review. The first-level review provides users with overall map browsing, macro-information review and understanding of the status information of ancient Bridges; the second-level review directly indexes to the individual digital file library of corresponding ancient Bridges according to demand through query and retrieval; the third-level review realizes text data review, three-dimensional image interaction, and scale and size scrutiny [2].

3. Conclusion

The rainy and humid weather in the south, coupled with the fact that wooden structures are mostly located in mountainous areas, where water vapor accumulates and is not easy to evaporate, accelerates the rate of wood deterioration. In addition, China is in a stage of rapid development, with a large number of people pouring into the city from the countryside, and the rural population is scarce. The lack of local technical personnel and the lack of original documents of wood structure buildings make the maintenance and repair of wood structure buildings face great challenges. Top priority is to organize professional teams into the country, the use of HBIM technology can assign timberwork building, do a good job in information processing for subsequent maintenance and repair to provide more effective information.

Bibliography

1. Han Sai and Wu Ci. (2022). *“Information Presentation of Condition Inspection for Architectural Heratage Based on HBIM: Taking Three Doty Rooms in Forbiddent City as an Example”*. Traditional Chinese Architecture and Gardens, 6, pp. 52-57.

2. Zhang Ziyi.(2023). *”Ovedrview of architectural heritage conservation applications on HBIM”*. DADA 2023, pp. 532-537

Heritage Building Information Modeling of San Sebastiano Gate in Rome

Tommaso Empler

Department of History, Representation and Restoration of Architecture – Sapienza University of Rome

tommaso.empler@uniroma1.it.

Abstract

The research focuses on the creation of a HBIM procedure of San Sebastiano Gate. An HBIM procedure is a virtual simulacrum, corresponding to what is present in reality, where all the information and data referring to San Sebastiano Gate are contained, from the digital geometric shape to the material consistency, from the state of conservation to the maintenance program, in a virtual environment. The core of the HBIM procedure is made up of federated 3D models related to each other in a data sharing environment such as the Common Data Environment (CDE).

Keywords: HBIM, Cultural Heritage, 3D modeling

1. Historical Introduction of San Sebastiano Gate

In the construction of the new walls, commissioned by Aurelian in the 3rd century AD, the extension of the road network made it necessary to build a large number of gates which, depending on the importance of the road they crossed, took on different architectural characteristics (Fig. 1).

The importance of Via Appia determines the original appearance and name of San Sebastiano Gate, which, like Flaminia way, Ostiense way and Portuense way, had two arches and an attic illuminated by arched windows with two semicircular towers on the sides. The façade is covered in travertine and the stairs, located in a central position inside the towers, allows access to the maneuvering rooms and to the crenellated terrace covering the rooms below.

The first transformations of the gate was carried out, with the rebuilding of the walls, by Honorius at the beginning of the 5th century AD and concern the renovation of the two towers which, built in a circular shape, incorporates the previous ones and are raised by two floors. The travertine façade between the towers remains unchanged, while on the internal side a double arch door is built consisting of two semicircular walls, which give rise to a security courtyard and probably connect the door to the so-called Drusus arch, one of the arches of the Antoninian aqueduct which serves the Baths of Caracalla and which at this point crosses Via Appia.

New entrances to the towers are opened in the two side walls and the internal courtyard is used not only for military functions, but also to house the offices and guards of the customs office for the control of goods.

In subsequent interventions, one of the two entrance arches is closed and, due to subsidence caused by the earthquake of 442 AD, the foundations of the gate is reinforced with the construction of two imposing quadrangular bastions that cover the first two levels of the towers. The curtain around the arch and the first floor of the bastions are covered with marble blocks which, as evidenced by the remains of the inscriptions engraved on some of them, are almost certainly removed from nearby monuments. In addition to the inscriptions, especially on the blocks on the east side, various protruding stones are visible, also present in Porta Pinciana, while from other protrusions functional to the lifting and installation of the blocks. The marble cladding of the first level is delimited by a frame while the rest of the door is made of brick.

The first floor of the attic is used as a maneuvering room for the portcullis which, by means of ropes, is lowered from above along the grooves made in the internal jambs of the entrance arch and ensured the closing of the door towards the inside.

Probably between the 5th and 6th AD, due to new structural failures, the front of the bastion of the west tower is rebuilt and the heavy masonry vaults, which divided the towers into three floors, is replaced by wooden shelves.

In the last construction phase, the towers and the attic above the entrance are raised by one level and, to cover the new rooms, a crenellated terrace is placed.

The gate, indicated in the Middle Ages as D'Accia, Datia or Dazza, in modern times takes the name of Porta San Sebastiano, in memory of the martyr buried in the catacombs with the same name.

Over the centuries, various historical events have taken place near the door or inside it.

During the pontificate of Benedict XIV, between 1749 and 1752, some restoration works are carried out which also involved the reconstruction of a large part of the battlements.

As the seat of the customs offices, the gate became the home of the custodial staff responsible for checking the goods which,

for various periods, is entrusted by the pontiffs to the noble Roman families, who are entitled to a part of the toll imposed on the goods introduced in the city and must ensure the maintenance of the same doors.

The door remained property of the Dazio until 1922 and in the years 1940-1943, despite the unfavorable opinion of the Antiquities and Fine Arts Division, it is granted as a private studio and home to the secretary of the fascist party Ettore Muti.

To adapt the rooms to the new destination, various renovation works are carried out such as the construction of wooden and masonry stairs, the reconstruction of the collapsed attics and the remaking of the brick and travertine floors with the placement of black and white figured mosaics in two rooms on the first floor.

In the years following the end of World War II, restoration and adaptation work began on the internal spaces to open the monument to the public which, since 1990, has housed the Museum of the Walls.

Currently the museum (Fig. 2), set up in the rooms of the first and second galleries and in the round rooms of the two towers, tells, with the help of models and educational panels, the history of the walls of Rome, from the Servian walls to the forts erected after the Unification, analyzing the different construction phases and the various defensive techniques used over the centuries.

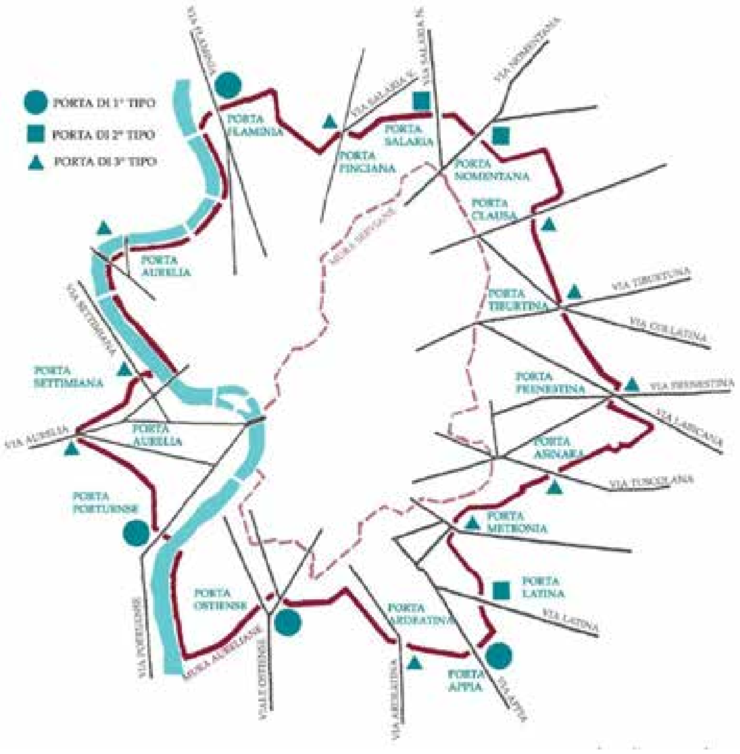


Fig. 1. Gates on the Aurelian Wall of Rome.

Fig. 2. San Sebastiano Gate today.

2. Methods-Case study

The research aims to create a Heritage Building Information Model (HBIM), containing informed data that can be used for a conservation process. The control and management of information takes place in a CDE (Common Data Environment), where there are federated models[1] related to each other, containing heterogeneous data usable in multiple application sectors. The relational system between the federated models is obtained through allowed connections or by the exchange of data in IFC format, or by the use of VPL (Visual Programming Language). The research focuses in this second direction, since the IFC format[2], to date, does not allow a perfect maintenance, and therefore transmission, of all the information referring to a single component, sometimes making the passage of data between different models complex[3].

The methodology involves the following steps:

1. Acquisition of geometric and material data;
2. Return and organization of data;
3. Realization of 3D mathematical models;
4. VPL connection;
5. Management of data and models in the Common Data Environment;
6. Extrapolation of data referring to the conservation process.

---

[1] "Federated model" means a model made up of several models, each of which refers to a specific disciplinary area. The models are related to each other thanks to the interoperability of BIM procedures, and to the IFC interchange format, which maintains the information referring to each of the individual models produced (https://www.01building.it/bim/centralita-modello-federato - actors-process-relations / last accessed September 2023).

[2] Industry Foundation Classes (IFC) data model is intended to describe the building and construction industry data (https://www.ibimi.it/ifc-cose-e-come-e-fatto/ last accessed September 2023).

[3] The term "model" has multiple definitions. The "physical model", in art or design, is used to fix a design idea in the form of a physical and real three-dimensional object. The "cognitive model" connected to the meaning of "idea", which is exercised with abstraction, with a rational, intellectual and logical reflection of the cognitive experience, defines the organization of a thought or functions placed together in sequence. The "3D model", which was born with the evolution of the IT environment, defines a digitization process, which contains information and data organized in three dimensions. The last definition is the meaning of "model" used in the paper (Empler, 2002).

3. Acquision of geometric and material data

Geometric data are acquired with an integrated TLS + drone photogrammetry procedure, while the material data are collected by means of orthophotos and sampling of the materials, which allow the preparation of USM sheets (Stratigraphic Wall Unit), with indications on the type of binders and of materials that make up the masonry of the surveyed architecture.

The description of the tools used for the acquisition and the pipeline of applications for the return is a fundamental part to set up and implement a reliable and consistent HBIM procedure with the proposed methodology.

Acquisition using TLS takes place with Faro Faro Focus 3D X 130 series instrumentation, with the aid of spherical targets of 13 cm in diameter. It is a phase difference laser scanner with integrated color camera, GPS multi-sensor, compass, height sensor and dual axis compensator[4]. The result of the acquisition are .fls files, native format of the laser scanner used.

A DJI - Mavic Pro Platinum[5] is used for drone photogrammetry.

The acquisition results are .jpg[6] image files.

Outcome of the acquisition of the material data are fact sheets with photographic images and two-dimensional representations in B/W with selection of the elements involved in the acquisition. These are accompanied by samples of materials taken, subjected to subsequent laboratory analysis[7]. Acquisition using TLS takes place with focus points located about 10 meters from each other on the outside, with an anti-clockwise trend with respect to the shape of the Gate, while on the inside, following the articulation of the structure. Acquisitions have as homologous points and planes recognizable both externally and internally, and spherical targets, which facilitate the subsequent recognition stage between various acquisitions with "Scene" restitution software, native to the Faro Faro Focus 3D Laser Scanner.

Acquisition with drone provides a preliminary assessment of the "Rules of Air" in the area affected by the flight. The area has only a limitation imposed by Ciampino Airport, with free flight allowed up to a maximum altitude of 25 m AGL (above ground level).

The flight plan is set in manual mode[8], following a trend that provides for an overlap of the individual photographs

---

[4] The tool has the following features:
- Range Focus3D X 130: 0,6 m - 130 m indoor or outdoor with vertical incidence on reflective surface (90%);
- Measurement speed (points / sec.): 122,000 / 244,000 / 488,000 / 976,000;
- Linear distance error1: ± 2 mm;
- Optical transmitter laser: Class;
- Integrated color camera: resolution up to 70 megapixel in color with automatic brightness adjustment (HDR);
- Dual axis compensator: provides level information for each scan; accuracy 0.015 °; measurement range ± 5 °;
- Height sensor: thanks to an electronic barometer it is possible to determine the relative height with respect to a reference point for each scan;
- Compass: the electronic compass identifies the orientation of the scan. A calibration function is also available;
- Inclinometer.

[5] The DJI – Mavic Platinum Pro has the following features:
- Dimensions (closed): 83 x 83 x 198 mm;
- Weight (with gimbal cap): 743g;
- Weight (without gimbal cap): 734g;
- Maximum speed (with remote control): 65 km/s in sport mode and in the absence of wind;
- Flight autonomy: 27 minutes (in the absence of wind);
- Maximum flight distance: 13 km;
- Maximum altitude 5 km;
- Internal memory: 8 GB;
- Camera sensor: 12 MP;
- Maximum video resolution: C 4K;
- Maximum remote control transmission distance: 4 km (CE compliant);
- Gimbal: mechanical with 3 axes;
- Noise: 4 dB.

[6] JPG: Joint Photographic Experts Group, compression format of images captured by digital cameras.

[7] Laboratory analyzes are performed by Arch. Elisabetta Giorgi, Technical Manager of the Materials Analysis Laboratory of the Department of History, Representation and Restoration of Architecture at Sapienza University of Rome.

[8] The choice of manual flight is due to environmental factors that cannot be controlled in the event of a pre-set flight in automatic mode. Throughout the Rome area, seagulls see drones, of the size used, as foreign elements and invaders of the airspace. For this reason, depending on the location and height of the flight, they are more or less aggressive. It should also be borne in mind that in the entire area of the Ancient Appia Park there are both Kestrel and the Peregrine Falcon,

for at least 40%. The photos are first acquired with a nadiral view and then with a 45° view on the horizon, with a north-south, south-north, east-west and west-east trend.

Characteristics of the drone used, DJI Mavic Pro Platinum, allows to get close to 1 m from the object to be photographed, thanks to a good compensation of the turbulence generated by the rotors and reflected by the opposite walls.

Material data (Fig. 3) are collected by carrying out orthophotos with a Canon EOS 1100 Reflex digital camera fixed on a tripod, and taking representative samples for analysis of the masonry, placed in numbered transparent bags.

Fig. 3. Masonry of San Sebastiano Gate.

4. Return and organization of data

Return of data (Fig.4) purchased with TLS involves the use of "Scene" software, native to Faro Faro Focus 3D Laser Scanner, and capable of automatically recognizing spherical targets[9] and connecting individual scans together. The result obtained is a 1: 1 scale point cloud, which is integrated by the point cloud produced by the photomodeling process, to which photos acquired with the drone are subjected. Format used for the interchange is .e57, able to keep information on the points, their color and spherical panoramas generated in the acquisition phase with TLS.

Photomodeling process is performed with "Agisoft Metashape" software, which generates, in succession, point clouds, mesh surfaces and tessellated surfaces. Point cloud produced, also exported in .e57 format, must be scaled and integrated with TLS acquisition.

The 3D model of photomodeling is transferred to the CDE.

To scale the model produced by photomodeling with that of "Scene", is used an open source application such as "Cloud Compare", where are taken coordinates of the targets on the ground present both in the acquisition with TLS and with photogrammetry. These coordinates are transferred to the photos containing the targets visible in "Agisoft Metashape", so that the point cloud generated is in the same scale as that generated by "Scene".

Both export files .e57 (at this point in the same scale), are imported into Autodesk Recap, to have a single model,

---

birds of prey capable of capturing with their claws a drone with the size of the DJI Mavic Pro Platinum.

[9] To support spherical targets it is possible to connect the homologous points of the acquisition points, placed in sequence, with the recognition of planes and points, as long as they are visible and present in sequential acquisition points.

in point cloud, perfectly integrated, where the cloud obtained with the photomodeling procedure it integrates all those parts not detected with the TLS from the ground.

The sampling of representative samples of the masonry, binders and brick or stone bricks, are subjected to laboratory analysis, in particular their characterization is performed with an optical microscopy reading.

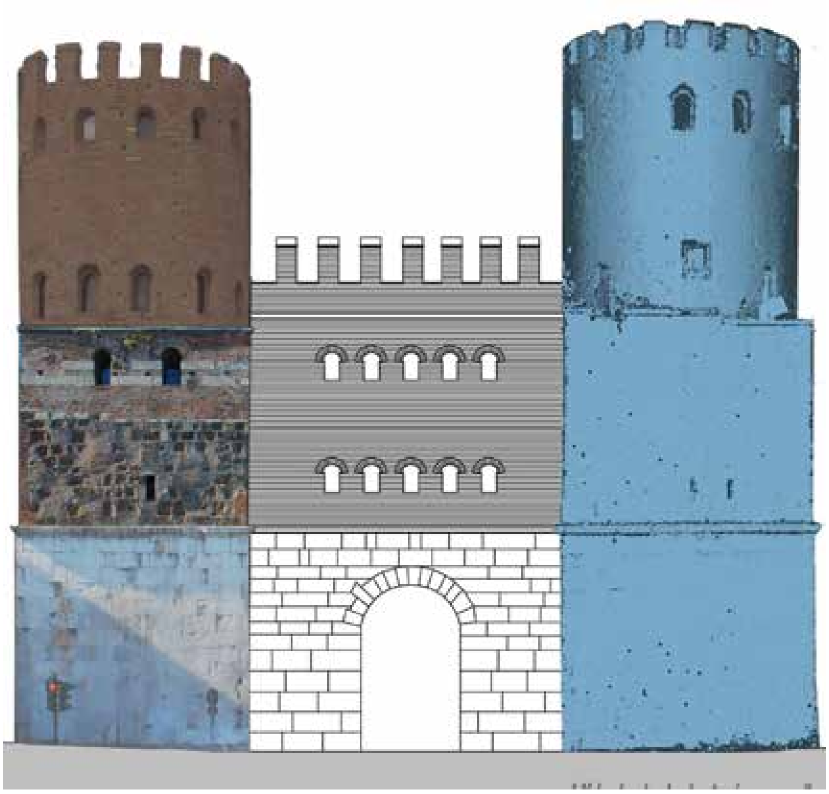


Fig. 4. Return of data: on the left 3D photogrammetry model, in the middle 3D vectorial model, on the right 3D point cloud model from TLS.

5. Realization of mathematical 3D models

Point clouds appear as a system of discontinuous points distributed in space, with x, y and z coordinates (with attributes, such as RGB values, for example).

3D modeling applications (mathematical or parametric modeling) directly acquire point clouds as objects, without having the ability to transform or modify them within their environment. The procedure is known as “scan to BIM” and is reductive with respect to the need to represent the geometric and material characteristics of architectural components belonging to historical objects with complex shapes. This fact occurs, in particular, in BIM modelers, where the informed parametric tools available tend to excessively exemplify the morphology of the acquired objects, such as, for example, a wall with an accentuated out of plumb, which is brought back to a parametric parallelepiped or the vaults inside the Gate.

This aspect is central to obtaining effective and reliable HBIM model of historic buildings and structures. An appropriate HBIM procedure must have the same characteristics as the object it denotes in a virtual way, both from the point of view of the shape and the attributes and characteristics of the various parts that compose it.

The importance of the representation of the artefact, understood as a cultural asset, is clearly evident if we consider how much the physical and material characteristics are necessary for the description of architectural objects, bearing values that must be preserved and handed down to future generations. The technical and technological peculiarities, the materials used and the layers that exist on the architectural heritage, tell the story of the monument intended as an emblem and expression of its time. Precisely for this reason, it is necessary to communicate effectively and faithfully reproduce the aspect of cultural heritage. The HBIM procedure is therefore a useful dissemination tool, an expression of the peculiar characteristics of layered architectures (Fig. 5).

Following the above indications, and operating with a mathematical 3D modeler[10], where a point cloud can be imported, there are two operating modes: segment and transform the point cloud into mesh by parts, based on the different architectural components; reconstruct with the 3D mathematical modeler the free forms present in the point cloud by parts, always referring to the different architectural components.

In both modeling modes, the "n" parts that make up each building component are created, such as, for example, the sequence: external cladding, external bearing part, filling part, internal bearing part, internal cladding.

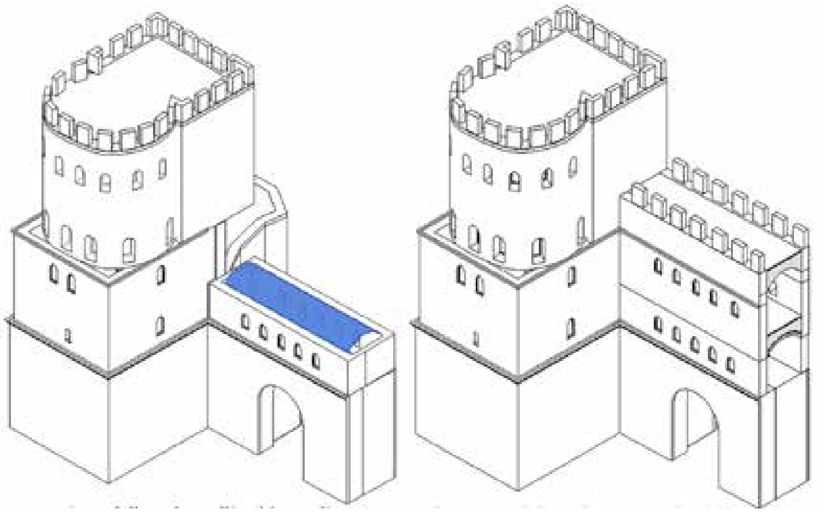


Fig. 5. Parametric 3D model of San Sebastiano Gate.

6. VPL connection between different information Return of data

Visual Programming Language[11] is a powerful means of visual connection between building parts and fact sheets containing information or data of any other nature.

A necessary and preliminary condition for any intervention on cultural heritage, performed according to information modeling procedures, is the formulation of a targeted methodological path in relation to the objective to be pursued, divided into work phases. The first action that must be performed is that relating to in-depth knowledge of the architectural object, which takes the form of the collection of information useful for recognizing the intrinsic and extrinsic characteristics of the artefact. Today's technologies provide multiple possibilities for classifying and collecting

---

[10] In the specific case Rhinoceros release 7.0, and the Rhino.Inside.Revit plug-in (https://www.rhino3d.com/inside/revit/1.0/ last accessed September 2023).

[11] A Visual Programming Language V.P.L. is a language that allows programming through the graphic manipulation of the elements and not through written syntax. A VPL allows you to program with "visual expressions" but also when you need to insert pieces of code (usually this function is reserved for mathematical formulas). The majority of VPLs are based on the idea "boxes and arrows" or the "boxes" (or rectangles, circles, etc.) are conceived as functions connected to each other by "arrows".

VPLs can be further classified, depending on how they represent functions on screen, in icon-based, form-based, or diagramming language. The visual programming environment provides everything you need to be able to "design" a program immediately; in relation to written languages the syntactic rules are practically non-existent. The advantages of visual programming are the ease of learning and the ability to view the status of the program during the debugging phases. Furthermore, parallel programming (if managed by the software) becomes almost "instinctive" and above all performed automatically. (https://it.wikipedia.org/wiki/Languaggio_di_programmazione_visuale last accessed September 2023).

information.

One of the possible ways of acquiring and transcribing information relating to real estate, proposed here, is based on the compilation of fact sheets specifically structured on spreadsheets useful for the development of qualitative and quantitative assessments, referring to the characteristics of the building. These "cards" are developed according to the specificity of the place, following assessments made by various professional figures who contribute to the achievement of in-depth knowledge of the place, following the principle of interdisciplinarity. In the case under examination, specific fact sheets were therefore prepared for the collection of information referable to the material characteristics of San Sebastiano Gate. The intent is to find a way of correlation between the "cards", previously described, and the three-dimensional object by generating textured meshes.

It should certainly be noted that among the many IT tools that can be used, in the field of cultural heritage management, there is still no fully consolidated effective exchange format. For this reason, it is desirable to hypothesize the use of additional components that make it possible to overcome this problem and ensure effective solutions by performing the arduous task of interchanging between different types of IT structures. Undoubtedly, the Visual Programming Language is one of the components that can be counted, which is able to direct the actions of the software through the graphic manipulation of the elements and not through written syntax (Fig. 06). In particular, using some specific software it is possible to create an effective connection between the fact sheet, previously formulated and compiled in relation to the information acquired with the evaluation of the characters of the Gate's walls, and the textured mesh model. The structure of the VPL code, "built" for the specific case study, consists of two main subgroups: the first dedicated to the transfer of the contents of the spreadsheets within the VPL language and the second intended for the association of each parameter to the individual portions of the artefact, previously identified and returned as independent digitized objects.

The first phase is structured starting from an operation that provides for the simplification of the fact sheet according to formats compatible with the VPL language. This first step, apparently not very relevant, is on the other hand a necessary condition for understanding the wall data of the visual programming language. The second subgroup, on the other hand, is functional to the effective association of any information with the selected mesh object.

Through the VPL connection of the Rhino.Inside.Revit plug-in, it is possible to report directly on the architectural 3D model, present in the CDE, the mapping of degradation.

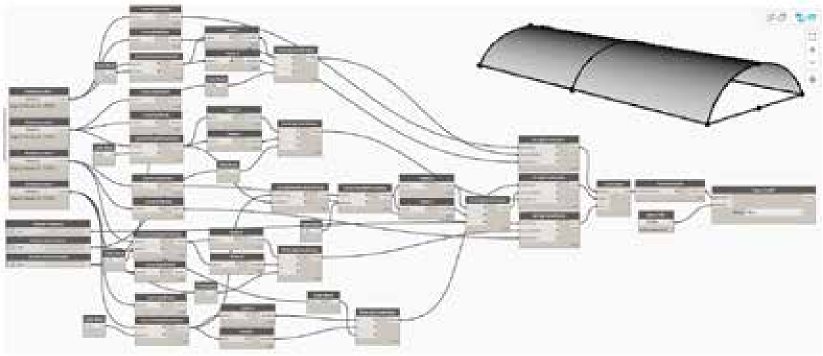


Fig. 6. VPL procedure for the reconstruction of a vault.

7. Management of data and models in a Common Data Environment

A CDE[12] is the central part of a HBIM procedure, it is the area that contains digital information and that centralizes the storage and access to project data, made up of federated models.

---

[12] The concept of the ACDat Data Sharing Environment has been introduced in Italy in recent years by the UNI 11337 standard and is defined as an "Environment for the organized collection and sharing of data relating to models and digital documents, referring to a single work and to a single complex of works". The legislation makes a clear reference to the Anglo-Saxon term Common Data Environment (CDE), introduced long ago by BS 1192: 2007, and over the years it has represented a tool that has facilitated the exchange of information flow between counterparties (https: // www.ingenio-web.it/29319-ambienti-di-condivisione-dati-acdat-focus-sulla-titolarita-di-tali-ambienti last accessed September 2023).

The data stored in a CDE originally consisted of BIM data and information. A CDE includes the Project Information Model (PIM) and the Asset Information Modeling (AIM), which concern graphical, non-graphical data and documents of any other nature associated with the HBIM procedure, such as: documents such as project contracts, estimates, reports, material specifications and other information relevant to the processes of design and construction, maintenance, conservation and enhancement.

A CDE is an inclusive repository of data generated by all those figures of experts who are able to iwork on the digital model in any capacity. Interested parties in the HBIM procedure can access the CDE anytime, anywhere using a computer, mobile phone, tablet or machines in the field.

Data contained in a CDE are manifold, as are their formats, the relationships are established with interchange formats, such as the IFC, or relationships between parts and complex components using the VPL described in the previous paragraph. In this way it is also possible to make the federated models generated for the definition of HBIM models communicate and relate to each other.

8. Extrapolation of data referring to the conservation process

The conservation process of San Sebastiano Gate is made possible thanks to the data contained in the federated model, which contains information on the state of decay and on the interventions to be carried out to carry out an organic scheduled maintenance program (Fig. 7). CDE of the HBIM model contains data on the nature of the binders present, and therefore to be reproduced, as well as on the types of masonry present. The federated model contains the 3D mapping of the degradation, quantity and quality of the work to be performed, in addition to the economic values and the time schedule to follow to conduct the intervention.

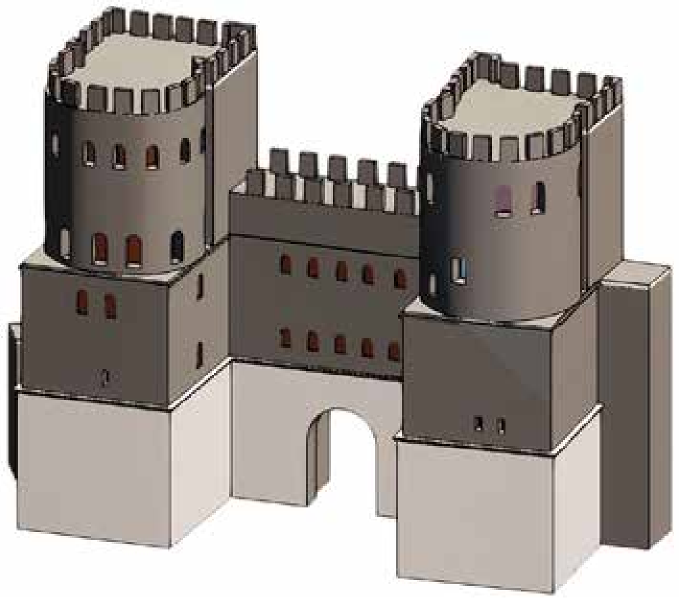


Fig. 7. Federated model of San Sebastiano Gate.

9. Conclusion

An HBIM procedure can be seen as an evolution of information modeling procedures known as BIM. If they are above all an operational and managerial character of the project and construction site phase, HBIM represents a 360° transition from the physical object to its digital replica. It is a tool for analyzing and modeling the interactions between people and the built environment. Its application to the field of built heritage not only indicates the possibility of interactions in real time, but also the possibility of managing a CDE composed of federated models organized, managed and interrogated in such a way as to have multiple answers, concerning both the construction sector but also that of communication and enhancement of the same structures. The application case on San Sebastiano Gate, thanks to a Scientific Collaboration Agreement between the Department of History, Representaion and Restoration of Architecture and the Capitoline Superintendency, also highlights how research must also be applied, going more and more in the direction of Third Mission.

Bibliography

De Angelis Bertolotti, R., Ioppolo, G., Pisani Sartorio, G. (1980). *“La residenza imperiale di Massenzio. Un contributo al Parco Archeologico dell’Appia Antica”*. In AA.VV. Catalogo della mostra. Roma: Istituto di Studi Romani.

Empler, T. (2002). *“Il Disegno Automatico tra progetto e rilievo”*. Roma: Officina Edizioni.

Empler, T., Caldarone, A., Fusinetti, A. (a cura di) (2021). “3D Modeling & BIM. Digital Twin”. Roma: DEI, TIpografia del Genio Civile

Empler, T., Fusinetti, A. (2020). *“Rappresentazione a rilievo nei percorsi museali”*. DISEGNO n. 6, p. 169-178.

GRAESSLER, I., PÖHLER, A. (2017). “Integration of a digital twin as human representation in a scheduling procedure of a cyber-physical production system”. In 2017 IEEE international conference on industrial engineering and engineering management (IEEM) (pp. 289-293). IEEE.

GRIEVES, M., VICKERS, J. (2017). “Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems”. In Transdisciplinary perspectives on complex systems (pp. 85-113). Springer, Cham.

ZHENG, Y., YANG, S., CHENG, H. (2019). *“An application framework of digital twin and its case study”*. In Journal of Ambient Intelligence and Humanized Computing, 10(3), 1141-1153, Springer, Cham.

Use of Historic BIM and GIS in landscape design and masterplanning

Mario Rossi   Arch. Chandni Jeswani

mario@astudiopro.com

chandni@astudiopro.com

Abstract

This paper presents a theoretical framework that demonstrates the value of Building Information Modeling (BIM) in the context of master planning and landscape architectural design. The proposed equation encapsulates the core concept of a theoretical framework which can justify and demonstrate the value of BIM towards design. Case studies are presented to validate the accuracy and effectiveness of the framework. Furthermore, the paper highlights the potential of extending this equation to optimize other works beyond master planning and landscape architecture design. This equation contributes to the understanding and application of BIM in various design domains, emphasizing its adaptability and effectiveness in achieving optimal outcomes.

Keywords: Building Information Modeling (BIM), Design optimization, Theoretical Framework

1. Introduction

Besides data-driven design, surveillance and maintenance, drone mapping, 3D printing, virtual real-ity, robotics and other digital innovations, Building Information Modelling or BIM has become an important part of the construction process in the past years, and in some parts of the world it is becoming standard and even obligatory (Bormann et al. 2015). Building Information Modeling (BIM) is a powerful digital tool that facilitates the creation, management, and exchange of information throughout the entire lifecycle of a project. Using Geographic Information Systems (GIS) is a valuable addition to BIM functionalities by providing spatial input and geospatial visualization, adding information on the construction site's surrounding environment that are essential for design decisions and approval processes By integrating the BIM planning processes into a geodatabase structure in a collaborative planning system, the corresponding information can be exchanged and processed very quickly. (.Schaller, Joerg & Gnädinger, Johannes & Reith, Leon & Freller, Sebastian & Mattos, Cristina. 2017). GIS is a decision-making environment for landscape architects at the regional and global levels. The real strength of GIS is its ability to manage large quantities of spatial data, and to provide the tools for querying and analyzing data (Bilous, L., V. Samoilenko, P. Shyshchenko, and O. Havrylenko. , 2021). GIS and BIM are the products of digitization of two subdisciplines of surveying and mapping, geodesy and engineering survey (Song, Yongze, Xiangyu Wang, Yi Tan, Peng Wu, Monty Sutrisna, Jack C. P. Cheng, and Keith Hampson, 2017).

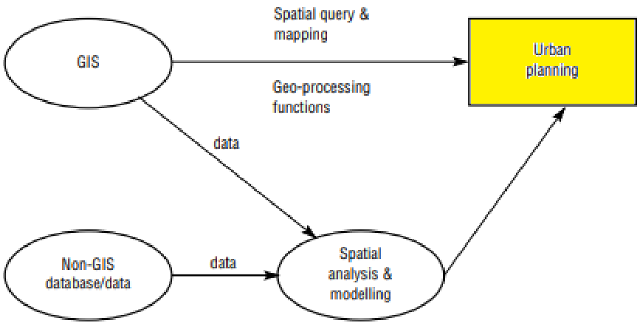


Fig. 1. Utilization of GIS in an urban planning framework.

The utilization of GIS as input can be in various ways, for example, the use of existing thematic datasets (e.g. via Web

Services) or by converting from existing databases or other monitoring systems (e.g. remote sensing) (Pietsch, Matthias., 2012), the use of drones for site mapping matched with historical data and images, use of climate data via EPW files etc. BIM and GIS both provide digital representations of architectural or environmental entities, their focuses are different. on buildings themselves while GIS are specialized in geospatial information outside buildings (Wang, Hao & Pan, Yisha & Luo, Xiaochun., 2019), therefore together they can provide a complete picture of the building and its context. Alongside the typical understanding of BIM-GIS combinations namely, "BIM leads and GIS supports", "GIS leads and BIM supports", and "BIM and GIS are equally involved" (Wang, Hao & Pan, Yisha & Luo, Xiaochun., 2019), we aim to propose a theoretical framework to understand the value of these integrations.

This theoretical framework aims to outline the key components and considerations for integrating BIM into landscape architecture design, master planning, and architectural design.

Inputs:

- Design professionals from landscape architecture, architecture, engineering, and planning disciplines.
- Project data including 3D models, specifications, schedules, and cost estimates.
- Software tools for 3D visualization, simulation, clash detection, and sustainability analysis.
- Protocols and standards for data management and information exchange.

Processes:

- Integrated Design Process: Collaboration and coordination among professionals using BIM as a platform.
- Data Management and Information Exchange: Establishing protocols for managing and exchanging project data.
- 3D Visualization and Simulation: Creating 3D models, visualizing designs, and conducting simulations.
- Parametric Design and Analysis: Applying parametric design principles to explore design options and optimize performance.
- Sustainability and Performance Analysis: Integrating sustainability analysis tools for evaluating environmental impact.
- Clash Detection and Coordination: Using BIM for identifying and resolving conflicts in design elements.
- Lifecycle Management and Facility Operation: Extending BIM for managing facility operation and future modifications.

Outputs:

- Enhanced collaboration and communication among design professionals.
- Organized and accessible project data throughout the lifecycle.
- Visualized and simulated 3D models for design assessment.

- Optimized design options and improved project quality.
- Informed decisions for enhancing sustainability and reducing environmental impact.
- Resolved conflicts and improved project efficiency.
- Support for facility operation, maintenance, and future modifications.

The theoretical framework emphasizes the importance of an integrated design process that brings together stakeholders from various disciplines, including landscape architecture, architecture, engineering, and urban planning. BIM acts as a collaborative platform, enabling seamless communication and coordination between different professionals involved in the project.

Therefore, both integrations are utilized in which GIS is used as an input and BIM as a part of the process. BIM can be used to manage the data during entire life-cycle of construction process. GIS can be defined as the information that related to the geography which provides the detail spatial data on specific location by using coordinates. By integrating these two platforms, BIM data can be representing in the real world (Basir, W. N., U. Ujang, Z. Majid, S. Azri, and T. L. Choon, 2020).

BIM allows for the centralized management of project data, including 3D models, specifications, schedules, and cost estimates. The framework emphasizes the need to establish clear protocols and standards for data management, ensuring that information is organized, accessible, and up-to-date throughout the project lifecycle. Effective information exchange protocols between different software tools and disciplines should be established to enable interoperability.

BIM provides the capability to create and visualize 3D models that represent both built and natural environments. This framework emphasizes the utilization of advanced visualization and simulation techniques to assess design options, analyze site conditions, and evaluate the environmental performance of the project. This includes using tools such as energy analysis, daylighting simulations, and urban microclimate studies.

The theoretical framework promotes the adoption of parametric design principles within the BIM environment. Parametric design allows for the exploration of various design options by defining and manipulating key parameters. By integrating parametric tools, landscape architects, architects, and master planners can efficiently evaluate different design alternatives, optimize performance, and enhance the overall quality of the project.

BIM can integrate sustainability analysis tools to evaluate the environmental performance of landscape designs, master plans, and architectural projects. The framework emphasizes the integration of energy analysis, water management, ecological impact assessment, and life cycle assessment tools within the BIM environment. This enables stakeholders to make informed decisions that reduce environmental impact, enhance energy efficiency, and improve overall sustainability.

BIM facilitates clash detection and coordination, ensuring that different design elements, such as buildings, landscape features, infrastructure, and utilities, are properly integrated. The framework promotes the use of clash detection tools to identify and resolve conflicts early in the design process, minimizing rework, reducing errors, and improving project efficiency.

Beyond the design and construction phases, the framework emphasizes the utilization of BIM for facility operation and lifecycle management. By integrating asset and facility management systems, BIM can support the ongoing maintenance, operation, and renovation of the built environment. This includes managing maintenance schedules, tracking asset performance, and facilitating effective decision-making for future modifications.

2. Methods-Case study

The equation can be proved by applying it to various projects, notable examples of our work like our proposal for the neighborhood of San Salvi in Firenze, (Florence), Italy, the beautification of the Hotel Le Royal Meridien in Dubai, UAE, the enhancement of the Hatta Heritage Area in Hatta, UAE, the landscape architecture master planning of the Qatar Science Park in Doha, Qatar and the Roberto’s Restaurant Terrace in DIFC Area, Dubai, UAE.

Case Study 1 - Le Royal Méridien Beach Resort & Spa, Dubai, United Arab Emirates

The Le Royal Méridien Beach Resort & Spa is a hotel and resort in Dubai, United Arab Emirates. Overlooking the pristine waters of the Arabian Gulf and set in 19 acres of landscaped gardens, with three swimming pools and recreational activities (Marriott Group, n.d.), it was built in 1994 and refurbished several times.

This ongoing landscape design project endeavors to transform the beachside surroundings of a prestigious hotel in Dubai into a harmonious integration of natural and built elements. The primary objective is to create a captivating and ecologically sustainable landscape that both complements the hotel's architectural grandeur, long legacy and enriches the guest experience with a serene and captivating ambiance. Dubai, renowned for its unparalleled architectural achievements, aspires to create a landscape design that echoes the city's cosmopolitan flair while seamlessly integrating with its natural coastal environment. This ongoing project aims to achieve a balance between aesthetics, sustainability, and functionality, offering guests an immersive experience that celebrates the beauty of the beachside locale. By incorporating principles of landscape ecology, biophilic design, and sustainable practices, the project seeks to redefine the relationship between human beings and the environment, fostering an appreciation for the region's unique ecological features.

The design philosophy for this project is to provide an inviting and engaging setting. The design team's approach embraces three key principles: ecologically sensitive landscape variety, resource efficiency, and aesthetic beauty and harmony. The landscape design aims to evoke a sense of tranquility and awe-inspiring beauty, harmonizing with the hotel's architectural elegance. The use of carefully curated materials, textures, and colors, inspired by the coastal environment, creates a seamless transition between indoor and outdoor spaces. Deliberately designed paths and viewpoints encourage guests to engage with nature and appreciate the serene coastal vistas, while intimate gathering spaces and landscape elements provide opportunities for relaxation and contemplation. It is an integration of scientific knowledge, artistic vision, and environmental stewardship.

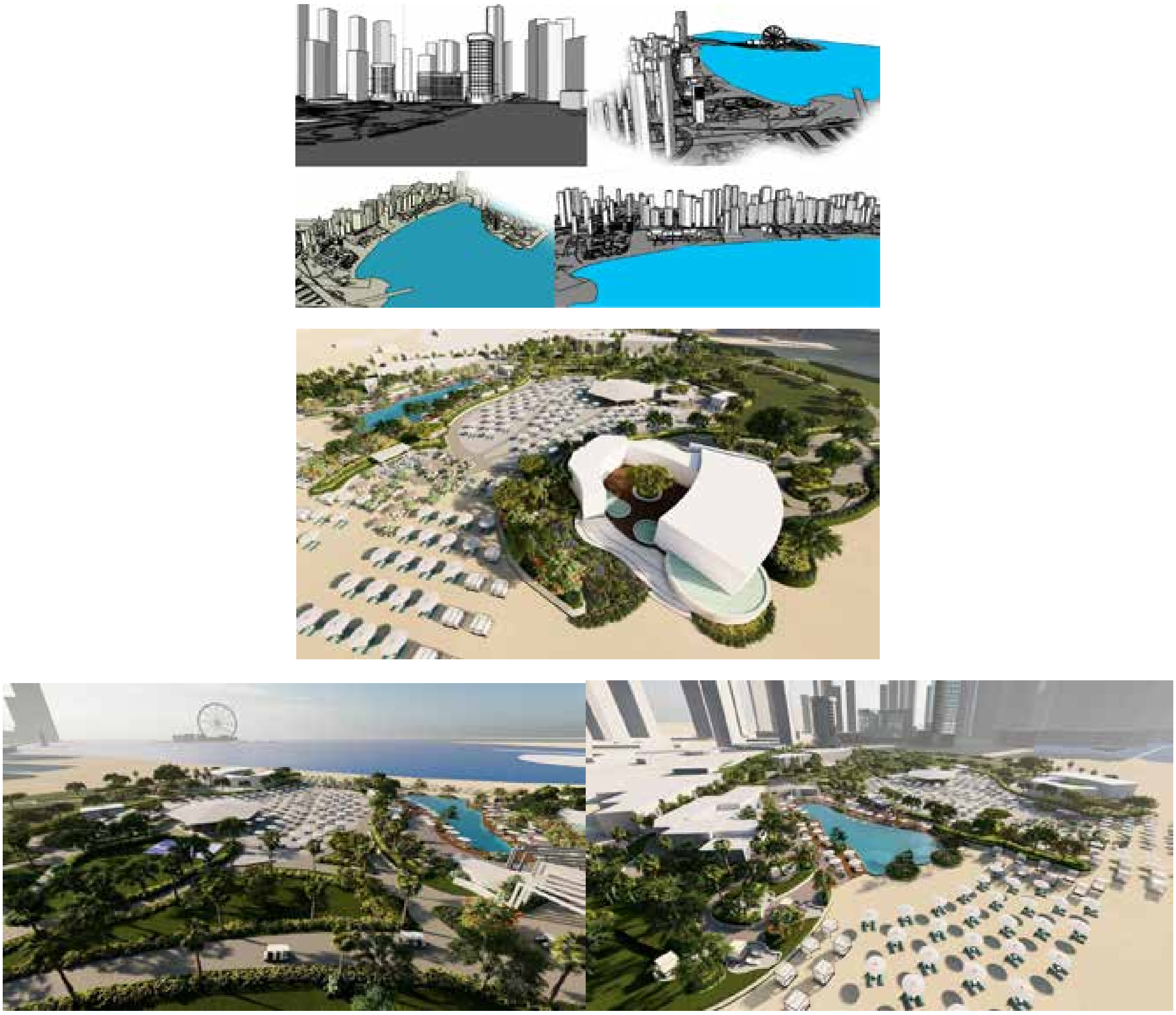


Fig. 2. Le Royal Meridien Jumeirah Beach, Dubai, United Arab Emirates.

Use of GIS and BIM

The use of GIS and BIM results in a sophisticated and data-driven approach to the design process.

GIS plays a crucial role in the initial stages of the design process by providing valuable geospatial data and analysis. Through GIS, we extracted essential information on the site's topography, land cover, hydrology, vegetation distribution, and other pertinent geographical attributes. This geospatial data facilitated comprehensive site analysis, allowing for informed assessments of ecological suitability, potential constraints, and critical landscape features. Additionally, GIS enabled the visualization of spatial data in the next stage, helping designers to create accurate site maps and 3D models, analyze various design alternatives, and assess potential impacts.

Furthermore, GIS aided in the selection of native plant species by considering factors such as ecological compatibility, adaptability to local conditions, and promotion of biodiversity. The integration of GIS data into the design process enabled a precise understanding of ecological patterns and interactions, thereby facilitating the creation of landscape designs that seamlessly harmonize with the natural surroundings. GIS also supported the identification and evaluation of potential impacts and constraints, such as protected areas, sensitive habitats, and regulatory restrictions, ensuring compliance with environmental regulations and promoting sustainable design practices.

BIM technology assumed a central role in the later stages of the design process, particularly concerning the integration of landscape design with the hotel's architecture. BIM involves the creation of a digital 3D model that encompasses both the built environment and the natural landscape components. This integrated model provides a comprehensive visualization of the project, allowing designers to assess the visual and functional relationships between various design elements. As the surrounding area including the buildings of the Dubai Marina and the far-off view of Ain Dubai, the 3D model was extended to include these to study the effect of landscape elements on the views. BIM also facilitated collaboration among different disciplines involved in the project, such as architects, landscape architects, engineers, and contractors. Through BIM, the design team effectively exchanged and managed information from the site, the client and regulatory authorities, ensuring seamless integration and coordination of design elements. Clash detection functionalities within BIM software helped to identify potential conflicts or clashes between landscape features and the hotel's architectural components. This early detection of clashes enabled efficient resolution, reduced rework, and optimized the design process.

In summary, the incorporation of GIS and BIM technologies in the design process for Le Royal Meridien enhances data-driven decision-making, fosters collaboration, and improves the overall efficiency of the design and construction processes. These advanced tools enable a comprehensive understanding of the site's characteristics, facilitate ecological integration, streamline project management, and contribute to the creation of a harmonious and visually captivating landscape design.

Case Study 2 - The Neighbourhood of San Salvi, Florence, Italy

Located in the vibrant city of Florence, Italy, the San Salvi neighborhood offers a captivating blend of history, culture, and architectural marvels. Situated in the central region of Tuscany, this area is known for its picturesque streets, charming squares, and remarkable buildings. It has a wealth of architectural treasures, ranging from ancient churches and palaces to traditional residential buildings. The streets are lined with cafes, shops, and local businesses, creating a lively and bustling atmosphere. With its rich heritage and a myriad of attractions, including the San Salvi area, the School of Psychology of the University of Florence and the Sant'Ambrogio Market nearby, the neighborhood offers a captivating experience for both residents and visitors.

Therefore, the San Salvi neighborhood in Florence, northeast of the historic centre (Editorial Staff, 2018) used for farming first, then for a psychiatric hospital/asylum, is a historically significant and culturally rich area with immense potential for urban development. We were involved in the masterplan redesign of the neighborhood, which would not only safeguard its history but also its position as a place of public use (Editorial Staff, 2018). We envisioned a beautiful neighborhood where lush greenery adorns the area, with carefully manicured gardens and pockets of green spaces interspersed throughout. We also wanted to allow views to the Arno River and to the nearby hills.

The utilization of Geographic Information Systems (GIS) and Building Information Modeling (BIM) proved to be instrumental in the landscape design and masterplanning proposal of the esteemed San Salvi neighborhood in Florence.

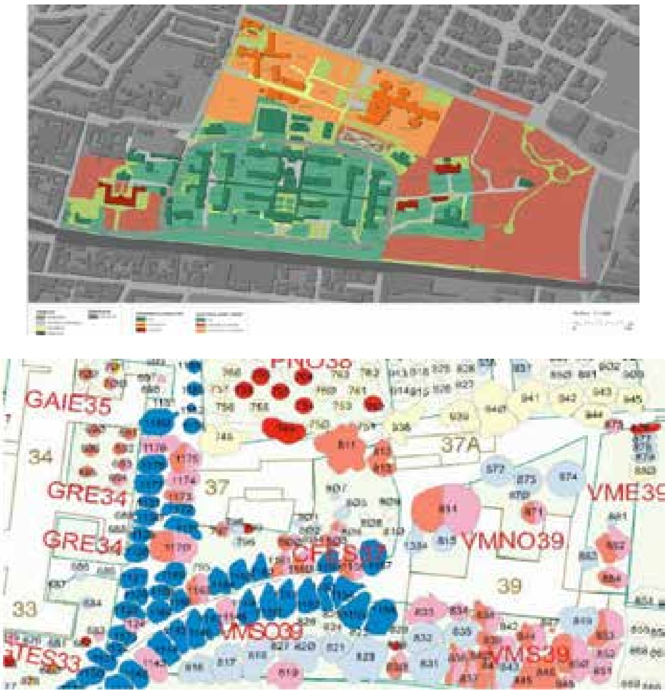


Fig. 3. San Salvi, Florence, Italy.

Use of GIS and BIM

By assimilating geospatial information pertaining to the San Salvi neighborhood, such as topography, land use, infrastructure, and environmental characteristics, GIS empowers experts to make informed decisions while harmonizing the natural and built environments. The integration of accurate data allows for a profound understanding of the locale's complex spatial relationships, facilitating the identification of optimal design solutions.

Furthermore, GIS enables the precise delineation and assessment of critical factors that influence landscape design, including hydrology, vegetation patterns, and transportation networks. By visualizing these elements in a spatial context through GIS, we ascertained potential constraints, identified areas of opportunity, and developed a holistic approach spanning human needs and the communication with existing infrastructure to the neighborhood's masterplan. GIS utilization through the use of various databases from municipal organizations ranging from cartographic maps and satellite imagery to geodatabases and land use records, free source data and site surveys both mechanical (tree assessment and forestry indicators) and natural, provided us with a comprehensive understanding of the existing landscape conditions which in turn empowered us to envision innovative design interventions that synergise with the site's unique attributes.

This integration also enabled us to conduct comprehensive terrain analysis, employing techniques such as digital elevation modeling (DEM), slope analysis, and view shed analysis. These methodologies elucidate the intricate topographical characteristics of the site, facilitating the identification of optimal placement for built structures, open spaces, and vegetation. Furthermore, the utilization of GIS enables the precise evaluation of land use patterns, infrastructure networks, and environmental factors, engendering a holistic understanding of the neighborhood's fabric and its potential for sustainable development.

BIM, a sophisticated digital modeling approach, complements GIS by providing a comprehensive framework for design synthesis and collaboration. By creating a three-dimensional, intelligent representation of the proposed landscape and built environment, BIM enabled us to simulate and analyze complex design scenarios with precision. This virtual environment encompassed detailed architectural components, intricate landscape elements, and advanced parametric modeling, allowing stakeholders to explore a range of design possibilities and make informed decisions that optimize functionality, aesthetics, and sustainability. The integration of BIM within the masterplan permits multidisciplinary collaboration among architects, landscape designers, urban planners, and engineers, ensuring a harmonious integration of infrastructure, green spaces, and built structures. Through the shared virtual environment, professionals evaluated the potential impacts of design decisions, simulated various scenarios and their climatic, natural and real performance, and optimized the selection and placement of the landscape elements. This collaborative approach fostered efficient communication, minimized errors, and enhanced the overall quality of the masterplan. By simulating energy consumption, daylighting, use of shading and water management systems, we made design decisions championing environmental stewardship. BIM also enabled the precise estimation of construction costs, material quantities, and project timelines, aiding in the establishment of realistic budgets and schedules and transparent communication.

These advanced technologies of GIS and BIM empower professionals to leverage geospatial data and create comprehensive digital representations, fostering an environment of informed decision-making, collaborative design, and sustainable development. We aimed to create a masterplan that seamlessly harmonizes with the site's context, historical significance, and social dynamics. The resulting design exemplifies a symbiotic fusion of technological innovation and creative excellence, cementing the San Salvi neighborhood as an exemplary testament to the convergence of science, art, and urbanism, resulting in an urban space that encapsulates the essence of Florence's cultural heritage while being modern in its execution and use.

The plan, after its release to the Client, became part of the Urban Planning Official Rules for the City of Firenze.

Case Study 3- Al Rahba Greenhouse, Abu Dhabi, United Arab Emirates

The Al Rahba Greenhouse is a state of the art greenhouse situated in Abu Dhabi, United Arab Emirates. The aim was to make a selection and propagation of a climate sensitive, research based and beautiful interior and exterior landscape palette. The project required climate, experience and comfort sensitive placement to address circulation of people will work, visit, enjoy and encounter the greenhouse precinct, the placement of trees, shrubs, their selection and the position of seating and rest areas. It also required a thorough understanding of existing to recommend and choose systems to create comfortable space for both the plants and the visitors. Bee farms were created on site, for eventual dissemination and creation of an ecosystem in which the plants can not only grow but flourish.

Fig. 4. Al Rahba Greenhouse, Abu Dhabi, United Arab Emirates.

Use of GIS and BIM

The Al Rahba Greenhouse project in Abu Dhabi, United Arab Emirates, showcases the exceptional use of Geographic Information Systems (GIS) and Building Information Modeling (BIM) to create a state-of-the-art, climate-sensitive, and research-based greenhouse. The project began with a comprehensive analysis of the site, incorporating a manual sun study to identify optimal positioning and marking wind direction and noise sources. This initial assessment was further enhanced through the utilization of a dynamic 3D model, enabling simulations based on data that could be extrapolated for any date and time.

The data obtained from the GIS analysis was effectively visualized through graphs, providing valuable insights into factors such as sun exposure, humidity levels, and other relevant parameters. The sketch masterplan was developed based on this data, ensuring a selection and propagation of plants suitable for the hot and humid climate of the region. The positioning of trees, shrubs, seating areas, and rest zones was carefully considered, taking into account the sun position and humidity data.

The plant selection process was driven by data inputs, and each chosen plant was assigned a code for integration into the BIM model. This integration allowed for precise representation and management of the plant species within the greenhouse design. Additionally, the 2D schematic design incorporated the chosen plants, providing a comprehensive overview of the greenhouse layout and planting arrangement.

The integration of GIS and BIM technologies resulted in a visually appealing and accurate 3D model that showcased the aesthetics of the greenhouse, including the specific types of plants and their arrangement within the space. The 3D model further facilitated the generation of informative sections, providing insights into the structural composition and design features.

The climate data obtained through the GIS analysis played a crucial role in designing an effective irrigation and humidity control system. By utilizing this data, researchers were able to create a model that optimized irrigation based on the hot and humid climate of the region, ensuring a comfortable environment for both plants and visitors. Furthermore, the climate analysis influenced the decision to utilize ETFE as the roofing material, maximizing natural light transmission while considering the specific environmental conditions.

In conclusion, the seamless integration of GIS and BIM technologies in the Al Rahba Greenhouse project enabled data-driven decision-making, precise design representation, and efficient resource management. By incorporating manual sun studies, dynamic 3D modeling, data analysis, and visualization techniques, the project achieved a remarkable synergy between climate sensitivity, aesthetic appeal, and user comfort. The Al Rahba Greenhouse stands as a testament to the successful integration of GIS and BIM, resulting in a sustainable and visually captivating greenhouse that thrives in the unique climate conditions of Abu Dhabi.

Case Study 4 - Villa Mezzapesa, Bari, Italy

With an emphasis on preserving the existing elements, the proposal strikes a balance between modern elegance and the timeless charm of the site. Every aspect of the design, from the placement of functional spaces to the preservation of the existing wall near the pool, has been thoughtfully curated and is based on data to create a seamless integration between architecture, technology and nature. The result is a captivating villa landscape that not only offers a serene retreat but also celebrates the unique character of the enchanting surroundings.

Fig. 5. Villa Mezzapesa, Bari, Italy.

Use of GIS and BIM

Located in Bari, Italy, this project exemplifies the successful integration of Geographic Information Systems (GIS) and Building Information Modeling (BIM) to optimize the design and construction processes. The project began with a comprehensive assessment of the existing site conditions, taking into account factors such as topography, vegetation, and infrastructure.

To accurately represent the site, GIS technology was utilized to gather and analyze spatial data, generating precise 3D models. Points generated through GIS mapping from the local municipality were incorporated into the BIM model, facilitating the creation of a level plane and ensuring accurate placement of the villa onto the site. This integration enabled us to visualize the proposed design in the context of the existing site conditions, allowing for informed decision-making and efficient use of available space.

The 3D model not only provided a visual representation of the project but also served as a valuable tool for various analyses. By conducting a radiation analysis on the model, we could estimate the solar exposure throughout the site, identifying areas suitable for specific functions to maximize client comfort and energy efficiency. Additionally, the model facilitated the measurement of cut and fill volumes, enabling the calculation of soil movement required for the project's construction.

The use of BIM technology allowed for the creation of comprehensive and detailed project proposals. Conceptual designs were visualized, showcasing the envisioned architectural and spatial elements. Schematic proposals, generated within the BIM model, provided a clear overview of the project's layout, including the connections between various components and the preservation of existing elements, such as the wall near the pool.

Throughout the design and construction phases, the integration of BIM and GIS technologies enhanced collaboration and coordination among stakeholders. The BIM model served as a centralized platform for data exchange, facilitating seamless communication between architects, engineers, contractors, and project owners. This resulted in improved efficiency, reduced errors, and enhanced project outcomes.

In conclusion, the successful integration of GIS and BIM technologies in this project played a crucial role in optimizing the design process and ensuring accurate site placement. The use of GIS provided valuable spatial data analysis, while BIM facilitated the creation of detailed 3D models, enabling precise design visualization, analysis, and collaboration. This seamless integration of technologies ultimately led to the successful realization of a well-planned and visually appealing project that harmonizes with the existing site conditions.

Future leanings

Use of OpenStreetMap in BIM and Rendering:

The integration of OpenStreetMap data in BIM and rendering processes enhances spatial context and visualization. Incorporating OSM's open and up-to-date geospatial information into BIM models enables accurate site placement and informed decision-making. This integration empowers designers to leverage the rich OSM data contributed by the community, improving visualization capabilities and contextual understanding. We are using it for visualization throughout the process, starting from deisgn options wherein we can evaluate options on the site in OSM according to the approaches and future directions reviewed by Pascal and Zielstra et al. (2014) and Liu et al. (2022) which studies BIM-GIS interoperability.

Generative AI Used in Landscape Design and Masterplanning:

Generative Artificial Intelligence (AI) revolutionizes landscape design and masterplanning by generating optimized design solutions. By training AI models on diverse datasets, designers can explore a range of design options quickly. Generative AI assists in discovering efficient design solutions, streamlining the process, and fostering creativity in landscape design. This is a more physical, parametric application to generate design options as used in Peña et al. (2021) and create design variations quickly to optimize design.

Site Analysis Using AI and ML Datasets:

Artificial Intelligence (AI) and Machine Learning (ML) techniques enable effective site analysis by extracting insights from large datasets. ML models trained on diverse data, such as geographic, environmental, and demographic information, enhance site selection, environmental impact assessment, and land use planning.

AR and VR through GIS and BIM:

Augmented Reality (AR) and Virtual Reality (VR), combined with GIS, visualization and BIM technologies, enhance spatial visualization and user experiences. AR overlays digital information onto the physical world, aiding design decision-making, while VR immerses users in virtual environments. The integration of AR and VR with GIS and BIM facilitates design analysis, stakeholder engagement, and simulation in various project phases.

GIS-Linked Sensors Linked with ML Datasets:

Integrating GIS-linked sensors with Machine Learning (ML) datasets enables real-time data collection, analysis, and decision-making. Sensors monitoring environmental parameters, when combined with ML datasets, provide insights for urban planning, environmental management, and infrastructure development. This integration enhances situational awareness and enables proactive decision-making based on real-time and historical data.

The integration of GIS-linked sensors enhances irrigation management by providing real-time data on soil moisture, weather conditions, and water usage. This integration enables precise control and optimization of irrigation systems, improving water-use efficiency and promoting sustainable irrigation practices.

3. Conclusion

This theoretical framework highlights the potential benefits of utilizing BIM in landscape design, master planning, and architectural design processes. By leveraging the collaborative and information-rich capabilities of BIM, professionals can enhance design efficiency, improve coordination, optimize performance, and foster sustainable development across the entire lifecycle of a project. The theoretical framework is consistently proven across our projects.

Bibliography

1. Basir, W. N., U. Ujang, Z. Majid, S. Azri, and T. L. Choon. "*The Integration of BIM and GIS in Construction Project – a Data Consistency Review.*" The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLIV-4/W3-2020 (2020): 107–16. https://doi.org/10.5194/isprs-archives-xliv-4-w3-2020-107-2020.
2. Bilous, L., V. Samoilenko, P. Shyshchenko, and O. Havrylenko. "*GIS in Landscape Architecture and Design.*" Geoinformatics, 2021. https://doi.org/10.3997/2214-4609.20215521034.
3. Borrmann, A., König, M., Koch, C. & Beetz, J. (Eds.) (2015), "*Building Information Modeling: Technologische Grundlagen und industrielle Praxis*". VDI-Buch. Springer. 591 p.
4. Carneiro, Joel, Rosaldo J. F. Rossetti, Daniel Valadão Silva, and Eugénio Oliveira. 2018. "*BIM, GIS, IoT, and AR/VR Integration for Smart Maintenance and Management of Road Networks: A Review*". https://doi.org/10.1109/isc2.2018.8656978.
5. Casali, Ylenia, Nazli Yonca Aydin, and Tina Comes. 2022. "*Machine Learning for Spatial Analyses in Urban Areas: A Scoping Review.*" Sustainable Cities and Society 85 (October): 104050. https://doi.org/10.1016/j.scs.2022.104050.
6. Editorial Staff. 2018. "*San Salvi and Seves Revamped | The Florentine.*" The Florentine. September 14, 2018. https://www.theflorentine.net/2018/09/14/san-salvi-seves-revamped/.
7. Neis, Pascal, and Dennis Zielstra. 2014. "*Recent Developments and Future Trends in Volunteered Geographic Information Research: The Case of OpenStreetMap*" Future Internet 6, no. 1: 76-106. https://doi.org/10.3390/fi6010076
8. Paul, Shimonti. "*Urban Planning and GIS.*" Geospatial World, July 23, 2018. https://www.geospatialworld.net/blogs/gis-in-urban-planning/.

9. Peña, M. T., Adrian Carballal, Nereida Rodriguez-Fernandez, Iria Santos, and Juan Antonio Pachón Romero. 2021a. *"Artificial Intelligence Applied to Conceptual Design. A Review of Its Use in Architecture."* Automation in Construction 124 (April): 103550. https://doi.org/10.1016/j.autcon.2021.103550.

10. Pietsch, Matthias. (2012). *"GIS in Landscape Planning"*. 10.5772/38996.

11. Schaller, Joerg & Gnädinger, Johannes & Reith, Leon & Freller, Sebastian & Mattos, Cristina. (2017). *"GeoDesign: Concept for Integration of BIM and GIS in Landscape Planning"*. Journal of Digital Landscape Architecture. 2017. 102. 10.14627/537629011.

12. Song, Yongze, Xiangyu Wang, Yi Tan, Peng Wu, Monty Sutrisna, Jack C. P. Cheng, and Keith Hampson. 2017. *"Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective"* ISPRS International Journal of Geo-Information 6, no. 12: 397. https://doi.org/10.3390/ijgi6120397

13. Wang, Hao, Yisha Pan, and Xiaochun Luo. *"Integration of BIM and GIS in Sustainable Built Environment: A Review and Bibliometric Analysis."* Automation in Construction 103 (2019): 41–52. https://doi.org/10.1016/j.autcon.2019.03.005.

14. "Welcome to Le Royal Méridien Beach Resort & Spa." Jumeirah Beach Hotel in Dubai | Le Royal Méridien Beach Resort and Spa. Accessed July 2, 2023. https://www.marriott.com/en-us/hotels/dxbbm-le-royal-meridien-beach-resort-and-spa/overview/.

15. Zhao, L., Mbachu, J. & Liu, Z. *"Developing an Integrated BIM+GIS Web-Based Platform for a Mega Construction Project"*. KSCE J Civ Eng 26, 1505–1521 (2022). https://doi.org/10.1007/s12205-022-0251-x.

Digital twin solutions in Bandung City: case studies of Dutch colonial heritage buildings

Nurtati Soewarno, Mustika K Wardhani

Department Architecture, Institut Teknologi Nasional Bandung-Indonesia

nurtati@itenas,ac,id; kwee@itenas.ac.id

Abstract

The increase in computer technology impacts all aspects, including architecture. In Indonesia, since the beginning of 2000, 2D modelling has been considered to need improvement in the design of buildings, especially buildings with high complexity. Switching the design and construction process to 3D models makes work in the field and building maintenance easier. The Dutch colonized Indonesia for a long time, leaving behind many buildings that have now been declared Cultural Heritage. Most of these buildings still survive today but generally do not have graphic documents. Increasing population and technology are driving change, especially in the city centre area where cultural heritage buildings are located. On the other hand, the charm of cultural heritage buildings attracts tourists. Therefore, maintenance and conversion measures are needed so that these buildings can support tourist needs, such as commercial functions. Building Information Modeling (BIM) is considered appropriate for creating documentation of these ex-colonial buildings so that if a change of function occurs, the authenticity of the building can be maintained. Apart from BIM, a Geographic Information System (GIS) currently can map geographically based building locations and provide tourist directions in a city. This paper will explain how combining the two methods, BIM and GIS, can show the location and describe the condition of Dutch Colonial heritage buildings in the central area of Bandung City, which is currently one of the tourist destinations in Bandung city. It is hoped that the combination of these two methods will simplify maintenance efforts and maintain the authenticity of the building even if the building has changed function. It is hoped that the new function of the building will support tourism activities, which will improve economic conditions. Combining these two methods is also hoped to maintain cultural heritage buildings as cultural heritage.

Keywords. : Heritage building, BIM, GIS, Tourism, City centre

Introduction

Bandung is West Java Province's capital, founded in 1811 by the Dutch Colonial Government. Bandung is located in remote mountains and is difficult to reach. The city's development began at the beginning of the 19th century, which was in line with the establishment of Bandung in 1906 as a Municipality (*gemeente*) (Kunto, 1984). The city centre area, as the embryo of the city according to Rossi in Soewarno & Wardhani (2023), was the first area to be built, which to this day, still functions as the city centre. Until now, the city centre area still has buildings left by the Dutch colonial government which have been declared a cultural heritage. Currently, the city centre area has become one of the tourist destinations in the city of Bandung. This paper will explain how BIM and GIS are integrated into the central area of Bandung. What is meant by the city centre area in this paper is the embryo of the city and its development or the area where Dutch people were active in the past. This area has been declared a cultural heritage area, and the objects raised are also cultural heritage buildings. The three objects are the Merdeka Building (Society Concordia) on Asia Afrika street (*Groote Post Weg*), Bank Jabar Banten (Dennis Bank) on Braga street (*Pedati Weg*) and Holy Cross Catholic Church on Achmad Yani street (*Groote Post Weg*).

To support tourism, some cultural heritage buildings have been converted into commercial functions, such as coffee shops, restaurants and other commercial functions (Soewarno et al., 2017). This transfer of function is based on the rules set by the Regional Government to maintain the authenticity of the building's architectural form and style. Considering that they are not young, renovation, rehabilitation and reconstruction measures are needed; for this reason, image documentation is very necessary. For this purpose, BIM or Building Information Modeling is used to describe the condition of the building, detect damage, and provide solutions without disturbing the authenticity of the cultural heritage building. According to The National Building Information Model Standard Project Committee (2014), Building Information Modeling (BIM) is a digital representation of a facility's physical and functional characteristics. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle, defined as existing from earliest conception to demolition. Another opinion is that Building Information Modeling (BIM) is a technology in the field of AEC (Architecture, Engineering and Construction) that is capable of simulating all the information in a development project into a 3-dimensional model.

Building Information Modelling (BIM) is an intelligent, 3D model-based tool that digitally represents a facility's physical and functional aspects. The Architecture, Engineering, and Construction (AEC) sector has long been plagued with high costs, slow deliverables, and lack of communication. Meanwhile, (Susanto, 2022) explained that BIM output varies; it can produce floor plans, cut drawings, detailed drawings, and animations up to a quantity of elements (volume of elements of a building). The other method is a Geographic Information System (GIS), which consists of spatially based and geographically oriented data components with a certain coordinate system as its reference basis. According to (Yousif & Burhan, 2021), that makes the need to develop the work of BIM and GIS together is very importance, when geographic information system (GIS) provides external modelling for city (map and geographic Information) also building information modelling (BIM) is providing internal modelling (3D modelling, material properties and its quantities for building).

In architecture, data collection of cultural heritage buildings cannot be separated from data collection of geospatial information where the buildings are. Information about the coordinates of the cultural heritage buildings is essential to facilitate searching for data on cultural heritage buildings, which are entirely a lot in Bandung. Besides the information on the coordinates of the location of the building, there is other complementary information, such as information on building designation and intensity, building architecture, environmental impact control, changes in function, form, physical characteristics, or additions to buildings. It is hoped that using these two methods, BIM and GIS, can be a solution for the sustainability of cultural heritage buildings in the central area of Bandung and other areas. Even though cultural heritage buildings are old, they still have charm and appeal. With proper maintenance methods, the existence of cultural heritage buildings can contribute greatly to a city's development. It is also hoped that this effort can preserve cultural heritage buildings as a colonial heritage for the Indonesian nation.

Methods-Case study

The Catholic Church 'Salib Suci' or Holly Cross

In the early 19th century, the city of Bandung grew rapidly. The city's development began in the east part of Bandung by establishing a new housing complex with various facilities, such as schools, hospitals, markets, sports facilities, and the Catholic Church of 'Salib Suci'. The Catholic Church' Salib Suci' or 'Holly Cross' was designed by architect Cuypers and was built in June 1929 by the Fermont Architect Bureau – Amsterdam the Netherland (*N.V Architecten-Ingenieurs Berau Hulswit en Fermont te Weltevredenen Ed. Cuypers to Amsterdam*). This church applied the Indische architectural style brought by the Dutch and was popular then. Nowadays, this building has already been established as Cultural Heritage Building. The Catholic Church 'Salib Suci' located at the corner of Kemuning Street and Jend Achmad Yani Street Bandung, West Java Province and the coordinate is -6.916110, 107.628486 (see figure 1) below:

Fig. 2. Location and old façade of Catholic Church as Heritage Building in Bandung

Building Information Modelling (BIM), a method in the Architecture-Engineering and Construction (AEC) project cycle, can simulate buildings digitally/virtually before the building is implemented. Information in BIM is used from the planning, implementation/construction, operational and maintenance stages to the demolition or renovation of buildings. As-built drawing information is building information following the implementation provided and used for building operation, maintenance, renovation, and demolition. According to Ern et al. (2020), BIM is time saving, cost saving, and provides a better management of project.

In general, cultural heritage buildings must have technical planning and as-built drawing documents when the building is completed. So that in order to preserve the building, it is necessary to prepare a technical document containing the following information:

a. Historical records

b. Photos, drawings, measurement results, notes, and videos.

c. Description and analysis of existing conditions and inventory of damage to buildings and their environment.

d. Suggestions for handling preservation.

The information on the preservation of the building is then compiled into a BIM-based digital information format, known explicitly as Heritage Building Information Modelling (H-BIM), a BIM-based method for documenting cultural heritage buildings. BIM is a technology that integrates all of the design information we are working on. When we change the floor height on the plan, the elevation is automatically in 3D. The appearance of the pieces will also change accordingly.

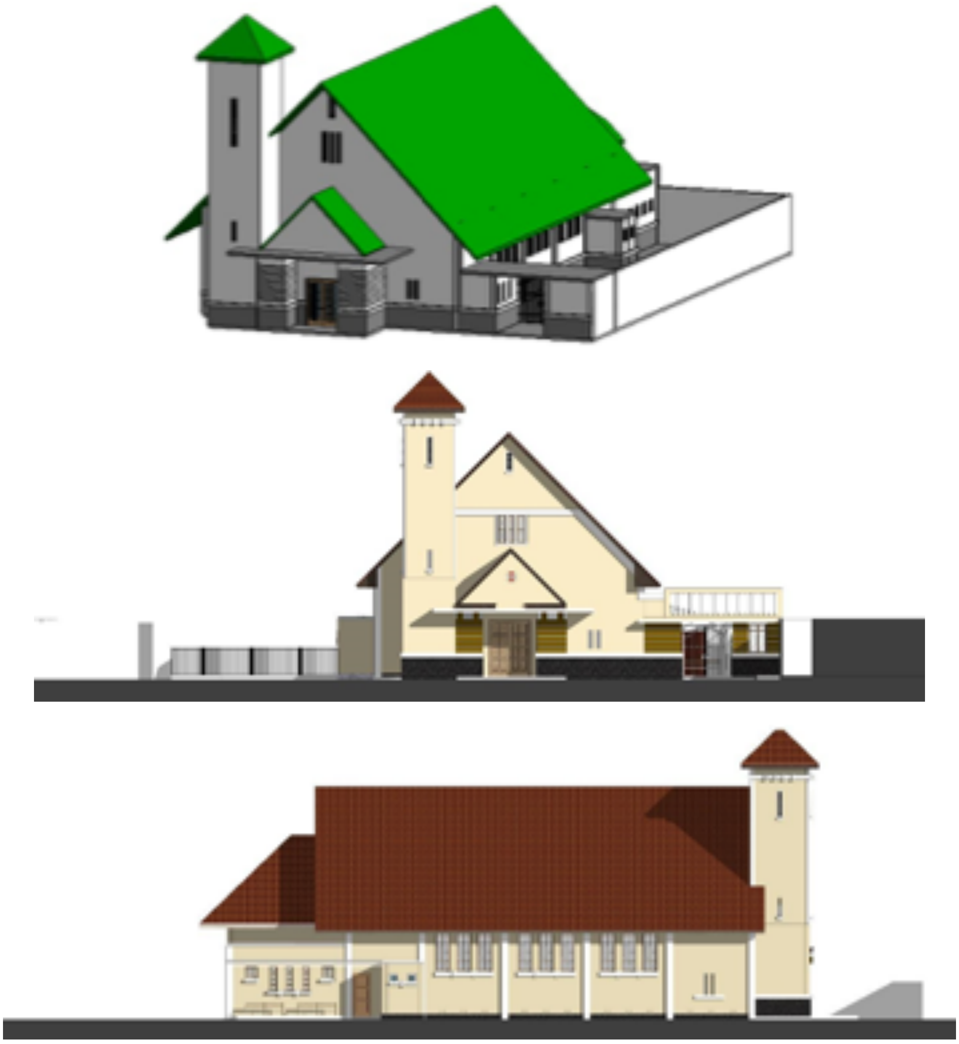


Fig. 2. Simple 3D modelling and final elevation

In the process, Revit has integrated with the world's current global locations, making sites where we will design interventions more accurately at suitable locations. Even for the previous version, users were able to calculate the efficiency of energy use in the selected location. However, for the latest version of Revit in 2024, Autodesk has yet to issue it. The reason for using Revit's BIM in re-modelling this cultural heritage building is that Revit has a variety of information and applications that tend to weigh less when compared to similar applications. In this case, the authors try to explain the advantages of using Revit in re-modelling the Salib Suci church located in Bandung:

1. Column

In practice, because cultural heritage buildings cannot be changed much, we must know very well what materials are used in manufacturing cultural heritage buildings so that we can restore them as closely as possible to building parts that are likely to be damaged by the ages. Columns are one of the essential parts of a building. When we use Revit, not only can we make the shape as similar as possible, but also, in terms of weight, bearing force, and dimensions, we can make the column as similar as before.

Fig. 3. Ground and Mezzanine Layout Plan

2. Walls

When we make a wall image on Revit, we can make it the same as what was on the wall of the previous building because when we make a wall on Revit, we can clearly and precisely see and know what composition we will make or restore.

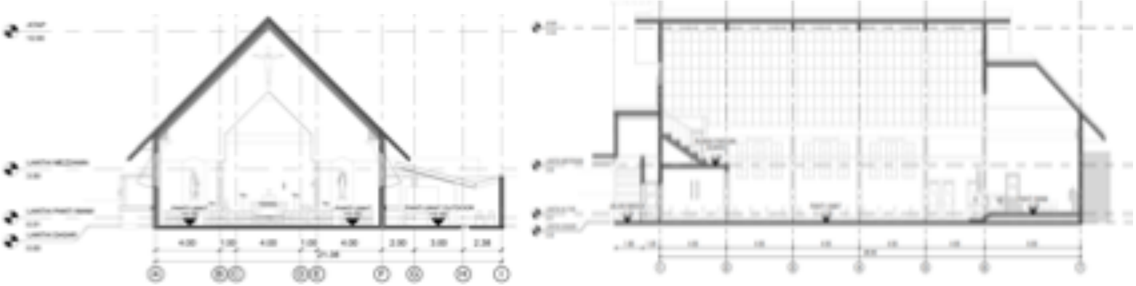


Fig. 4. Building section

3. Roof

The roof is one of the parts that can distinguish the type of a building. By recreating the roof structure on Revit, we can make the same roof as before in terms of slope, frame, and the type of roof we use because when we use Revit, we can use a truss system where the distance and size of the truss will be the same between one another.

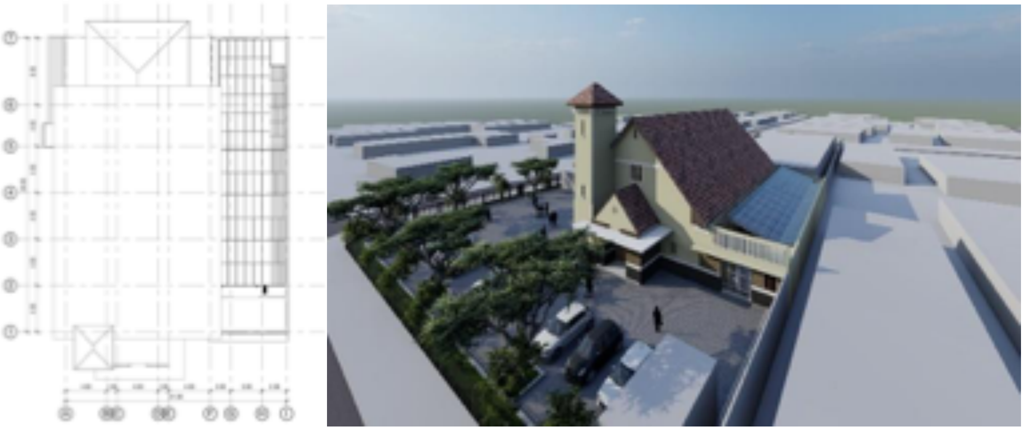


Fig. 5. Roof Plan construction and final 3D visualisation

After conducting analysis using BIM to be able to produce working drawings that are integrated into each material component, then GIS-based analysis is carried out to see at a macro level the distribution of class A cultural heritage buildings in Bandung and what the pattern looks like to support the tourism concept in the central area of Bandung city. Data collection of cultural heritage buildings cannot be separated from data collection of geospatial information where the buildings are. Information about the coordinates of the cultural heritage buildings is essential to facilitate searching for data on cultural heritage buildings, which are entirely a lot in Bandung. Besides the information on the coordinates of the location of the building, there is other complementary information, such as; information on building designation and intensity, building architecture, environmental impact control, changes in function, form, physical characteristics, or additions to buildings. This information is then stored in layers of geospatial information known as a Geographic Information System (GIS). The stages of GIS analysis are as follows:

1. *Analysis of the distribution of locations between cultural heritage buildings (class A) and their proximity to public facilities in Bandung*. The first step is to determine the location of the distribution of cultural heritage buildings (class A) in the city of Bandung (marking by red dots). According to regulations, 254 cultural heritage buildings are spread across Bandung, with the following distribution (see figure below). The purpose of determining the location distribution between cultural heritage buildings is related to their proximity to several observation indicators, such as public facilities, parking pockets, and green open spaces, which aim to provide geographic information on location distribution.

Fig. 6. Locational distribution between Cultural Heritage Buildings class A in Bandung City

In the kernel density analysis above, there are indicators of closeness, namely in the range 1-5, where the darker the colour that appears (dark blue), the closer the cultural heritage buildings are spread over an area. The kernel density analysis above shows that the darkest point is included in the area of Braga Street, where case studies for BIM studies will be carried out at this point.

2. Analysis of location distribution between Cultural Heritage Buildings and the proximity of transportation ranges and

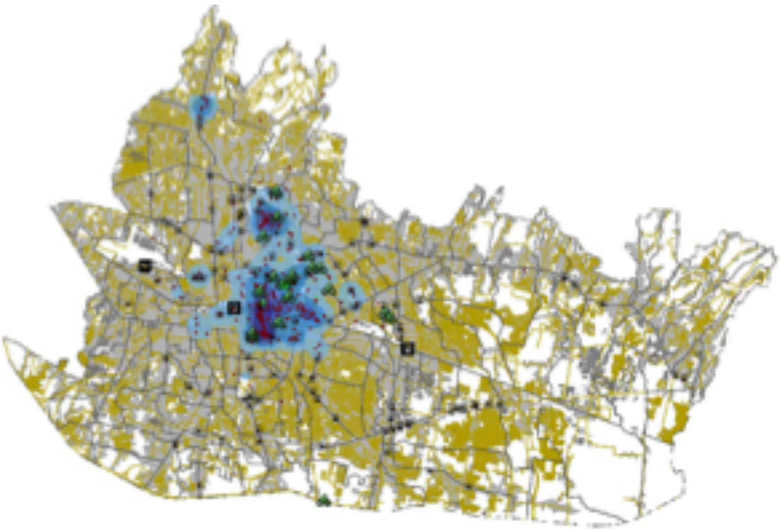


Fig. 7. Locational distribution between Heritage Buildings and public transport points (focus on airplane, bus, train, and bicycle station called *Boseh*)

The map above shows that the distribution of cultural heritage buildings is supported by the proximity of public transportation facilities, namely trains and buses. The proximity to reach the availability of bicycles is also added to see how a smart city system is formed by reducing carbon monoxide and making pedestrians and cyclists active.

3. *Classification based on land use*. There are various groupings of areas, as seen in the attribute points of cultural heritage buildings. This classification display will help architects record cultural heritage buildings with specific typological and morphological characteristics according to the area classification such as commercial area, governmental, or education area.

4. *Furthermore, building classification is carried out based on how it changes its function (Morphology)*. Various functional changes can be displayed on a map, which can be important information for architects and urban planners to see how buildings are transformed according to current needs. In this research, 4 case studies were selected where the current function still retains its old position, such as museums, banks, restaurants, and churches.

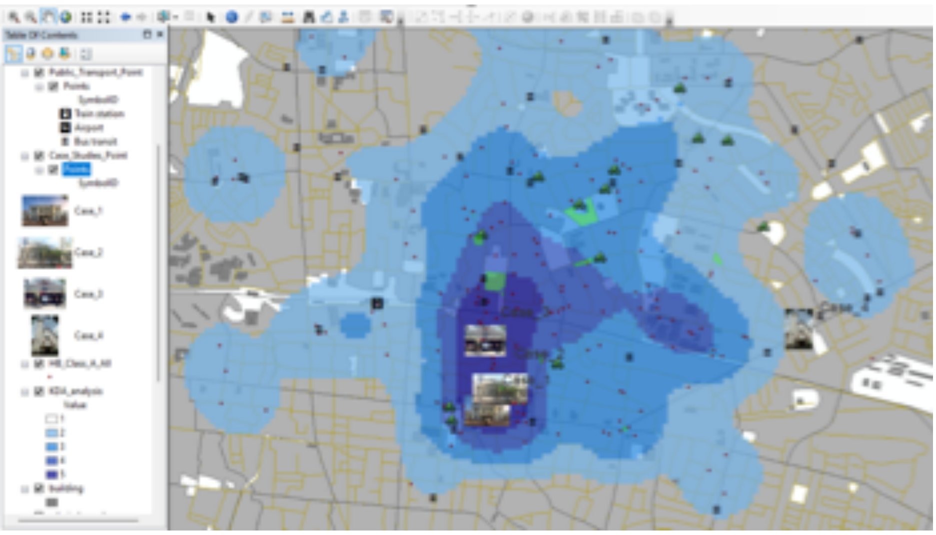


Fig. 8. The location of case studies 4 which discussed in more detail in BIM

Using mix methods analysis with the help of BIM and GIS can provide a micro and macro picture of cultural heritage buildings in a city with colonial heritage. The findings of this study can be a reference for developing the concept of smart tourism and its integration with environmentally friendly modes of transportation, as well as the affordability of one site with supporting public facilities.

Conclusion

The time the Dutch Colonial Government lived in Indonesia left traces that can still be seen today, one of which is buildings scattered in several big cities, one of which is Bandung. The ex-Colonial buildings are located mainly in the city centre area. These buildings have been declared cultural heritage buildings that must be preserved. As time passes, the central area becomes a tourist destination. Several facilities, such as hotels, coffee shops and restaurants, are needed to accommodate tourists' needs. The density of the city centre makes it impossible for new development to be carried out; therefore, changing the function of buildings is the right solution.

For this reason, a method is needed to document cultural heritage buildings to maintain their authenticity before the conversion process occurs. Combining the two BIM methods is appropriate for creating documentation for cultural heritage buildings. This documentation is needed primarily to support maintenance, renovation and rehabilitation activities so that the authenticity of the shape and style of the building can be maintained. In the case of rehabilitation, the replacement of materials or other elements is attempted to be closer to the original. The development of the ex-colonial area in Bandung, which tends to become a tourist destination, requires a direction map regarding the locations of cultural heritage buildings. Therefore, applying the GIS method is suitable as an accurate guide for tourists who want to visit cultural heritage buildings in the city of Bandung.

Bibliography

Ern, P. A. S., Ooi, Y. Y., & Al-Ashmori, Y. Y. (2020). Comparative Study On The Perspective Towards The Benefits And Hindrances Of Implementing Building Information Modelling (BIM). *International Journal Of Sustainable Construction Engineering And Technology*, 11(1), 194–205.

Kunto, H. (1984). *Wajah Bandoeng Tempo Doeloe* (I). PT Granesia.

Soewarno, N., Hidjaz, T., & Virdianti, E. (2017). *Adaptive Reuse As An Effort To Preserve An Historical District: A Case Study Of The Braga Corridor In The City Centre Of Bandung, Indonesia*. 89–100. Https://Doi.Org/10.2495/Sc170081

Soewarno, N., & Wardhani, M. K. (2023). The Transformation Of Shophouse As An Effort To Continue The Trading Tradition In Pasar Baru Area, Bandung. *ARTEKS : Jurnal Teknik Arsitektur*, 8(1), 115–124. Https://Doi.Org/10.30822/Arteks.V8i1.1976

Susanto, A. (2022, July 18). *Manfaat BIM Dalam Proses Perencanaan Bangunan.* https://Www.Uii.Ac.Id/Manfaat-Bim-Dalam-Proses-Perencanaan-Bangunan/

The National Building Information Model Standard Project Committee (2014)

Yousif, A. N., & Burhan, A. M. (2021). Benefit And Challenge Of Integrating BIM With GIS In Iraqi Construction Projects. *IOP Conference Series: Materials Science And Engineering*, 1105(1), 1–14. Https://Doi.Org/10.1088/1757-899X/1105/1/012091

General Conclusions

Federico Cinquepalmi

Benefits of GIS and BIM integration, towards a future of fully integrated technologies for advanced management of Built Environment

Since the beginning of the fourth industrial revolution, the advent of digitization, innovative technologies, and new materials, along with the gradual rise of new, highly automated construction techniques, have transformed the way of planning all kind of infrastructures and Cities, to be designed, built, managed, and operated for a completely new approach to built environments, conceived in general as more efficient, safe, monitorable, and therefore sustainable.

The different scales of analysis of urban systems and built environments increasingly require the maximum integration of advanced technologies, both for managing the existing buildings and infrastructures and for planning new ones. Skyrocketing developments in the field of Information and Communication Technologies (ICT), as well as advanced applications of artificial intelligence, robotics, nanotechnology, and additive manufacturing have now led the industry of construction into a new digital era, and further integration of larger-scale analysis such as data and information generated within the earth observation related sectors, seems to be in the next future a promising path to follow.

However, the present more substantial limit of all those technologies, to available available for a simplified and combined daily use, it appears both technical and technological, but also related to the availability of appropriate workforce. All the existing technologies mentioned above have been available since quite few times. Still, their use requires a non-always accessible massive data management and storage capacity, needed in order to be effective and effectively predictive, switching from a contingency intervention on already ongoing projects, towards a standard preliminary predictive approach, able to simulate the behavior of complex infrastructures and advanced building systems, able to compose the upcoming mosaics of future cities.

The already mentioned fourth industrial revolution considered in close relation with the built environment sectors, highlights how Digital Twin Models seem to be the most promising approach for the improvement of management of complex urban systems, in which now live more than 50 percent of the planet's population, with a projection towards 2050 of more than the 68 percent and even more, consuming 75% of global primary energy and producing most of the pollutants in the Global environment.

Facts and figures of the Twenty-first Century urban scenarios, clearly shows that the battle for sustainability would be won or lost within the cities and advanced integrated technologies seem to be the most promising path to follow for achieving that goal. United Nations general assembly, recognizing the cruciality of such matters, decided for the first time in 2005 to focus the attention on urban sustainability, updating the global strategy for sustainable development with the document: "Transforming our World: the 2030 Agenda for Sustainable Development", establishing a goal n. 11 dedicated to urban issues, stating that: "Making cities safe and sustainable means ensuring access to safe and affordable housing, investment in public transport, creating green public spaces, and improving urban planning and management in a participatory and inclusive manner[1].", as a necessary step in order to establish a sustainable future for Planet Earth there.

The human factor in such a complex scenario plays a fundamental role, both in terms of the education of each citizen to sustainability principles, as well as of those working for the management of complex urban ecosystems. Initiatives such as the Sapienza GIS/BIM international summer school, already at its fourth edition, are precisely addressing this matter, contributing to the improvement of future workforce for built environments management, and in this light the professional figure of a 4.0 project manager seems to be mandatory to address the future challenges of built environments.

---

[1] UN General Assembly 2005, Transforming our World: the 2030 Agenda for Sustainable Development (A/RF.S/70/1), New York, p. 18.

GISBIM
INTERNATIONAL
SUMMER SCHOOL

20
23

Lectures and notes
for a digital
integrated design

ISBN 979-12-210-5546-7

9 791221 055467