Lecture Notes
in Geoinformation and Cartography

LNG&C

Alias Abdul-Rahman
Ivin A. Musliman
Imzan Hassan
Ainn Zamzuri *Editors*

Advances in Geoinformation Sciences

Springer

Lecture Notes in Geoinformation and Cartography

The Lecture Notes in Geoinformation and Cartography series provides a contemporary view of current research and development in Geoinformation and Cartography, including GIS and Geographic Information Science. Publications with associated electronic media examine areas of development and current technology. Editors from multiple continents, in association with national and international organizations and societies bring together the most comprehensive forum for Geoinformation and Cartography.

The scope of Lecture Notes in Geoinformation and Cartography spans the range of interdisciplinary topics in a variety of research and application fields. The type of material published traditionally includes:

- proceedings that are peer-reviewed and published in association with a conference;
- post-proceedings consisting of thoroughly revised final papers; and
- research monographs that may be based on individual research projects.

The Lecture Notes in Geoinformation and Cartography series also includes various other publications, including:

- tutorials or collections of lectures for advanced courses;
- contemporary surveys that offer an objective summary of a current topic of interest; and
- emerging areas of research directed at a broad community of practitioners.

Alias Abdul-Rahman · Ivin A. Musliman ·
Imzan Hassan · Ainn Zamzuri
Editors

Advances in Geoinformation Sciences

Springer

Editors
Alias Abdul-Rahman
Department of Geoinfirmation
Universiti Teknologi Malaysia
Johor Bahru, Malaysia

Ivin A. Musliman
Department of Geoinformation
Universiti Teknologi Malaysia
Johor Bahru, Johor, Malaysia

Imzan Hassan
Department of Geoinformation
Universiti Teknologi Malaysia
Johor Bahru, Johor, Malaysia

Ainn Zamzuri
3D GIS Research Lab
Universiti Teknologi Malaysia
Johor Bahru, Johor, Malaysia

ISSN 1863-2246 ISSN 1863-2351 (electronic)
Lecture Notes in Geoinformation and Cartography
ISBN 978-3-031-86653-1 ISBN 978-3-031-86654-8 (eBook)
https://doi.org/10.1007/978-3-031-86654-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

First, we would like to thank all contributors to this book. The book contains chapters deal with the most recent research and development in geoinformation science and accepted for presentation at the Geoinformation Week 2024 International Conference as part of the Joint International Conference event (in conjunction with FIG Commission 5, FIG Commission 7, FIG LADM & 3D LA, and UN-Habitat STDM Conferences). In brief, themes of 34 chapters are 3D Buildings Modelling, UAV based Mapping, Geo-based Artificial Intelligence / Deep Learning, Marine Information System, Satellite based Image Processing & Analysis, and GIS & Land Administration. All accepted chapters were reviewed by the experts of the disciplines. We would like to thank all reviewers for their insightful comments and suggestions where their inputs elevate the quality of the chapters. We also hope these contributions able to provide new knowledge in geospatial science and trigger more interesting research in the near future.

September 2024

Alias Abdul Rahman
Muhammad Imzan Hassan
Ivin Amri Musliman
Ainn Zamzuri

Local Organizing Committee

Abd Halim Hamzah
Ainn Zamzuri
Alias Abdul Rahman
Ivin Amri Musliman
Kelvin Tang Kang Wee
Muhammad Imzan Hassan
Othman Zainon
Ramzi Abdillah
Stephen Ling Jin Huat
Suzanna Noor Azmy
Tajul Ariffin Musa
Wan Anom Wan Aris

Reviewers

Alias Abdul-Rahman (Malaysia)
Abd Halim Hamzah (Malaysia)
Abdelhamid Fadil (Morocco)
Ainn Zamzuri (Malaysia)
Alexis Richard Claridades (Philippines)
Ariel Blanco (Philippines)
Ayin Tamondong (Philippines)
Ben Gorte (Australia)
Chien Zheng Yong (New Zealand)
Gurcan Buyuksalih (Turkiye)
Hassan Rhinane (Morocco)
Ihab Hijazi (Germany)
Ivin Amri Musliman (Malaysia)
Jeark Principe (Philippines)
Jesper Paasch (Sweden)
Kamal Agharroud (Morocco)
Kean Huat Soon (Singapore)
Kelvin Kang Wee Tang (Malaysia)
Khalid Al Kalbani (Oman)
Mehdi Maanan (Morocco)
Mehmet Alkan (Turkiye)
Mohsen Kalantari (Australia)
Muhammad Imzan Hassan (Malaysia)
Muhammad Zulkarnain Abd Rahman (Malaysia)

Omar Alami (Morocco)
Othman Zainon (Malaysia)
Pawel Boguslawski (Poland)
Peter van Oosterom (Netherlands)
Rosalie Reyes (Philippines)
Serdar Bayburt (Turkiye)
Sisi Zlatanova (Australia)
Suhaibah Azri (Malaysia)
Trias Aditya (Indonesia)
Uznir Ujang (Malaysia)
Volker Coors (Germany)

Contents

List of Contributors

Amir Sharifuddin Ab Latip College of Built Environment, Universiti Teknologi MARA, Shah Alam, Malaysia

Ramzi Abdillah Lands and Surveys Department Sarawak, Kuching, Malaysia

Alias Abdul Rahman 3D GIS Research Lab, Faculty of Built Environment & Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia;
Department of Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Rizqi Abdulharis Bandung Institute of Technology, Bandung, Indonesia

Muhammad Luqman Ahmad Affandi Geospatial Imaging and Information Research Group (GI2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

Mahiuddin Alamgir Geoscience and Digital Earth Centre (INSTeG), Research Institute of Sustainable Environment (RISE), Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Malaysia

Nur Surayatul Atikah Alihan Geospatial Imaging and Information Research Group (Gi2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

Awan Amal Lands and Surveys Department Sarawak, Kuching, Malaysia

Madeline Anak Ambit Lands and Surveys Department Sarawak, Kuching, Malaysia

Michael Moses Apeh Department of Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Malaysia;
Department of Surveying and Geoinformatics, Federal Polytechnic, Idah, Nigeria

Abg Ahmad Azlan Abg Ariffin Lands and Surveys Department Sarawak, Kuching, Malaysia

Wan Anom Wan Aris Geomatic Innovation Research Group, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Iskandar Puteri, Malaysia

Suzanna Noor Azmy Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia;
Geoscience and Digital Earth Centre, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Mohamed Benayad Geoscience Laboratory, Department of Geology, Faculty of Science Aïn Chock, University Hassan II, Casablanca, Morocco

Erica Benya Billy School of Geomatics Science and Natural Resources, College of Built Environment, Seattle, US;
Hurricane Geo Inspection Survey Sdn Bhd (HGIS), Kuala Belait, Darussalam, Brunei

Sulaiman Budin Lands and Surveys Department Sarawak, Sarawak, Malaysia

Gurcan Buyuksalih Institute of Marine Sciences and Management, Istanbul University, Istanbul, Türkiye

Marouane Ouazani Chahidi Department of Geology, Faculty of Sciences Aïn Chock, Hassan II University, Casablanca, Morocco

Sim Choon Cheak SD Guthrie Berhad, Telok Panglima Garang, Selangor, Malaysia

Musa Muhammad Chindo Faculty of Built Environment & Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia;
Department of Survey & Geoinformatics, Federal Polytechnic Nasarawa, Nasarawa, 962101 Nigeria

Pei-Cheng Chen National Yang Ming Chiao Tung University, Hsinchu, Taiwan

Malumbo Chipofya Faculty ITC, University of Twente, Enschede, The Netherlands

Walter Dachaga Technical University of Munich, Munich, Germany

Walter Timo de Vries Technical University of Munich, Munich, Germany

Ami Hassan Md Din Geospatial Imaging and Information Research Group (GI2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

Saad Farah Geoscience Laboratory, Department of Geology, Faculty of Science Aïn Chock, University Hassan II, Casablanca, Morocco

Zineb El Faraj Department of Geology, Faculty of Sciences Aïn Chock, Hassan II University, Casablanca, Morocco

Nursyafiqah Jessica Georgeson Department of Water and Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Skudai, Johor, Malaysia

Rosmadi Ghazali School of Geomatics Science and Natural Resources, College of Built Environment, Shah Alam, Malaysia

Cassendra Gilbert Faculty of Sport Science and Recreation, Shah Alam, Malaysia

Serene Anak Joseph Goyang School of Geomatics Science and Natural Resources, College of Built Environment, Shah Alam, Malaysia

Mohammad Hanif Hamden Geospatial Imaging and Information Research Group (GI2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

Laaziza Hammoumi Geoscience Laboratory, Department of Geology, Faculty of Science Aïn Chock, University Hassan II, Casablanca, Morocco

Dzuren Hamzah Lands and Surveys Department Sarawak, Sarawak, Malaysia

Alfita Puspa Handayani Bandung Institute of Technology, Bandung, Indonesia

Mohd Faizury Abol Hassan Lands and Surveys Department Sarawak, Kuching, Malaysia

Noordyana Hassan Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia;
Geoscience and Digital Earth Centre, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Mazlan Hashim Geoscience and Digital Earth Centre (INSTeG), Research Institute of Sustainable Environment (RISE), Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Malaysia;
Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Malaysia

Nouriddine Houran Green Energy Park (GEP), Benguerir, Morocco

Stephen Ling Jin Huat Lands and Surveys Department Sarawak, Kuching, Malaysia

Nurul Hazrina Idris Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia;
Geoscience and Digital Earth Centre, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Zamri Ismail Geospatial Imaging and Information Research Group (Gi2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

Syarif Abdul Asa'ad Jairin Geospatial Imaging and Information Research Group (Gi2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

Ismail Rakip Karas Department of Computer Engineering, Karabuk University, Karabuk, Türkiye

Chaymae Khaloua Geoscience Laboratory, Department of Geology, Faculty of Science Aïn Chock, University Hassan II, Casablanca, Morocco

Mayuree Nasa Khan Faculty of Tourism and Hotel Management, Mahasarakham University, Kantharawichai, Thailand

Muhammad Ghaly Kurniawan Faculty ITC, University of Twente, Hallenweg 8, 7522 NH Enschede, The Netherlands;
Ministry of Agrarian Affairs and Spatial Planning/National Land Agency, Jakarta, Indonesia

Rafeah Legino College of Creative Arts, Universiti Teknologi MARA, Shah Alam Selangor, Malaysia

Claudia Lindner Kadaster International, Amsterdam, The Netherlands

Safia Loulad Department of Geology, Faculty of Sciences Aïn Chock, Hassan II University, Casablanca, Morocco

Mehdi Maanan Geosciences Laboratory, Faculty of Sciences-Ain Chock, Hassan II University, Casablanca, Morocco

Mohd Razali Mahmud GeoCoastal Research Unit (Gi2RG), Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Mohd. Rizaludin Mahmud Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia;
Geoscience and Digital Earth Centre, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Nursuhaili Najwa Masrol SD Guthrie Berhad, Telok Panglima Garang, Selangor, Malaysia

Myriame Virginie Matius University Teknologi Malaysia, Skudai, Johor, Malaysia

Wong Miliw Lands and Surveys Department Sarawak, Kuching, Malaysia

Ahmad Hamidi Mohamed College of Built Environment, Universiti Teknologi MARA, Shah Alam, Malaysia

Nur Hafizah Mohammed SD Guthrie Berhad, Telok Panglima Garang, Selangor, Malaysia

Mohd Radhie Mohd Salleh Department of Water and Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Skudai, Johor, Malaysia

Mickcy Mandang Anak Morgan Lands and Surveys Department Sarawak, Sarawak, Malaysia

Muhammad Abdul Hakim Muhamad School of Geomatics Science and Natural Resources, College of Built Environment, Shah Alam, Malaysia

Ivin Amri Musliman University Teknologi Malaysia, Skudai, Johor, Malaysia;
Department of Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia;
GIS Research Lab, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Wahyu Marta Mutiarasari 3D GIS Research Lab, Department of Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Ilya Khairanis Othman Department of Water and Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Skudai, Johor, Malaysia

Hanis Rashidan 3D GIS Research Lab, Faculty of Built Environment & Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia;
GIS Research Lab, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Abd Wahid Rasib Geospatial Imaging and Information Research Group (GI2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

Mohamad Hezri Razali College of Built Environment, Universiti Teknologi MARA, Shah Alam, Malaysia

Hassan Rhinane Geosciences Laboratory, Department of Geology, Faculty of Sciences-Ain Chock, Hassan II University, Casablanca, Morocco;
Geoscience Laboratory, Faculty of Science Aïn Chock, University Hassan II, Casablanca, Morocco;
Department of Geology, Faculty of Sciences Aïn Chock, Hassan II University, Casablanca, Morocco

Fatin Nabihah Syahira Ridzuan Geospatial Imaging and Information Research Group (Gi2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

Abdelilah Rochd Green Energy Park (GEP), Benguerir, Morocco

Hajah Siti Romiza Romali Lands and Surveys Department Sarawak, Kuching, Malaysia

Nur Nadhirah Rusyda Rosnan SD Guthrie Berhad, Telok Panglima Garang, Selangor, Malaysia

Siti Hayatunissa Saminan Lands and Surveys Department Sarawak, Sarawak, Malaysia

Bakeri Samsudin Lands and Surveys Department Sarawak, Sarawak, Malaysia

Mohd Zunica Mohd Sapi'ee Lands and Surveys Department Sarawak, Kuching, Malaysia

Radzuan Sa'ari Department of Water and Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Skudai, Johor, Malaysia

Shamsuddin Shahid Department of Water and Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Johor, Malaysia

Ching Yen Sim Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Mohamed Rabii Simou Geosciences Laboratory, Faculty of Sciences-Ain Chock, Hassan II University, Casablanca, Morocco

Vijaya Subramaniam SD Guthrie Berhad, Telok Panglima Garang, Selangor, Malaysia

Saiful Aman Sulaiman College of Built Environment, Universiti Teknologi MARA, Shah Alam, Malaysia

Abdul Rauf Abdul Rasam School of Geomatics Science and Natural Resources, College of Built Environment, Seattle, US

Mohd. Nadzri Md. Reba Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia;
Geoscience and Digital Earth Centre, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Kelvin Kang Wee Tang Geomatic Innovation Research Group (GnG), Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Tee-Ann Teo National Yang Ming Chiao Tung University, Hsinchu, Taiwan

Dimo Todorovski Faculty ITC, University of Twente, Enschede, The Netherlands

Mat Nizam Uti Kolej Alam Bina, Universiti Teknologi Mara Cawangan Perak, Seri Iskandar, Perak, Malaysia

Dudy Darmawan Wijaya Geodesy Research Group, Faculty of Earth Sciences and Technology, Institute ofTechnology Bandung, Bandung, Indonesia;
Geodetic Science, Engineering and Innovation Research Group, Faculty of Earth Science and Technology, Institute of Technology Bandung, Bandung, Indonesia

Nurul Nadiah Yahya Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia;
Geoscience and Digital Earth Centre, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Hao Yu National Yang Ming Chiao Tung University, Hsinchu, Taiwan

Mohd Iskandar Yusof Lands and Surveys Department Sarawak, Kuching, Malaysia

Ahmad Razali Yusoff Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Skudai, Johor, Malaysia

Hakima Zair Department of Geology, Faculty of Sciences Aïn Chock, Hassan II University, Casablanca, Morocco

Ainn Zamzuri 3D GIS Research Lab, Faculty of Built Environment & Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Samir Zouhri Department of Geology, Faculty of Sciences Aïn Chock, Hassan II University, Casablanca, Morocco

3D Buildings Modelling

The Third Dimension of GIS and LADM – Current Status and Perspectives

Alias Abdul Rahman(✉), Ainn Zamzuri, Hanis Rashidan, and Wahyu Marta Mutiarasari

3D GIS Research Lab, Faculty of Built Environment & Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
alias@utm.my

Abstract. This paper describes the overall trends in 3D geoinformation and the Land Administration Domain Model (LADM). Several aspects of these domains, such as data collection, processing, modeling, databasing, and visualization, are under investigation by researchers in academia or industry. Their works have been reported in international meetings and conferences, which have discussed increasingly advanced methods and techniques. In general, 3D geoinformation has advanced considerably, as is seen in current discussions within the 3D GIS community and the LADM and 3D Land Administration (LA) group. Conferences, workshops, and specialized user group meetings worldwide provide the latest research and development on the subject. This paper highlights the most recent findings on these two major domains in 3D geoinformation and provides insights into possible future developments.

Keywords: 3D geoinformation · LADM · 3D data fusion · Semantic modeling

1 Introduction

Geoinformation science has existed since the 1960s as a simple system to manage geographic objects for environmental research in North America, specifically Canada [1]. Later, additional systems were researched and developed by the community. Initially, these systems were categorized as 2D due to the nature of data at that time. These days, systems can handle spatial data in more than two dimensions; they also have more possibilities in terms of processing and visualization, as reported by [2]. The research and development of 3D GIS domains began around the mid-1990s when several major spatial object primitives were explored and recognized as 3D spatial objects; thus, a proper data model could be established. Several data models have been reported since then, such as spatial theory by [3] and other models by [4]. These models have since been further developed for greater flexibility in object and relationship connections. These connections between objects provide a better understanding of the 3D situations we perceive in the real world. An increasing number of research groups in academia and industry (vendors) have pursued greater performance in the processing and databasing stages. Here, a database's data structure and object indexing play a vital role in making the related processes and analyses faster, as reported by [5].

A. Abdul-Rahman et al. (Eds.): GeoWeek 2024, LNGC, pp. 3–16, 2025.
https://doi.org/10.1007/978-3-031-86654-8_1

Another important aspect of 3D GIS is semantic labeling (assigning and validation) of 3D buildings, which provides an accurate and fast way of recognizing information about the objects. The trend indicates the utilization of machine learning and deep learning to assist in the labeling process, as mentioned by [6]. This process requires large datasets to develop a robust segmentation model to achieve the desired outcome. Technological advancements have opened doors for further research on the automation and refinement of semantic labeling processes, making it possible to handle complex and large-scale 3D spatial datasets more efficiently. Moreover, integrating artificial intelligence with 3D GIS has facilitated improvements in data acquisition, generation, and the overall quality of geospatial processes.

3D building generation has been investigated for quite some time, especially in the context of acquisition techniques. However, research on combining techniques in one computing environment is lacking, as reported by [7]. Recent research shows that the accuracy of the combined techniques (fusion) could be improved by using a Laplacian algorithm. The optimal configuration of this fusion method is a subject of significant discussion, as reported by [8]. Ensuring high accuracy and completeness in 3D models is both essential and challenging when utilizing different datasets. One of the key challenges lies in developing effective data integration methods to generate 3D models from these varied datasets, such as the integration of multi-source point clouds as proposed by [9]. In the future, these valuable 3D models can be used in various applications such as urban planning and land management.

The integration of land and 3D spatial objects, as offered by the Land Administration Domain Model (LADM), results in better data modeling for managing and disseminating information. Thus, this integrated model (with well-defined classes) is an effective and reliable land management system, as reported by several researchers such as [10–12]. The LADM has the potential to be further developed to address more advanced situations and other international standards and formats, including CityGML, CityJSON, BIM/IFC, and INTERLIS.

In general, four main aspects of the 3D GIS domain have been investigated: spatial data acquisition, spatial data processing, spatial databases, and visualization, similar to what has been researched thus far in the 2D domain. These investigations aim to generate more advanced spatial data modeling and visualization concepts and techniques. The community is also investigating interoperability and standards related to 3D spatial data—for example, to share and disseminate data and information. 3D geoinformation research has been investigated in academia and by major software vendors.

Section 2 describes the status and perspective of 3D GIS. Section 3 describes the status and perspective of LADM. Finally, Sect. 4 concludes the paper.

2 3D GIS

The third dimension of geoinformation has been explored and investigated since the mid-1990s [13–15]. GIS improves upon simple 2D data capability by being able to handle and manage point cloud data (from LiDAR and other similar data collection systems). The goal is better processing with fast algorithms; databases should also be able to perform searches quickly. Smart indexing for spatial records and objects is of prime importance

for many research groups in academia and industry (software development houses). As reported by [2], digital twins and 3D city models are a significant research trend in the community. In Germany, TU Munich and HFT Stuttgart researchers have presented on CityGML 3.0, while the University of Melbourne group has investigated the same model for 3D underground land administration. These proceedings address point clouds and 3D building reconstruction, and BIM and GIS continue to be research topics in the community. One particularly interesting paper on the use of CityJSON for energy demand calculation examined JSON as an alternative (or a complement) for CityGML, and other works have described 3D indoor navigation for pedestrian interaction purposes (all of the preceding papers are discussed in [16]). We also acknowledge that several groups in the 3D geoinformation domain are investigating 3D data fusion and the semantic modeling of 3D buildings.

2.1 Data Fusion for 3D Models

3D models representing 3D objects can be generated from datasets like images and point clouds. Achieving accurate and complete 3D models is challenging due to the weaknesses of each spatial data acquisition method and the presence of occlusions. Thus, the fusion of several datasets has been utilized to overcome these weaknesses and subsequently generate complete 3D models, as demonstrated in [17, 18]. Point cloud datasets are commonly integrated with iterative closest point (ICP) registration. However, post-processing of this ICP registration reveals some limitations, including stratified redundancies [19] and gaps within the interconnected regions [9]. Consequently, enhancing 3D fused models to achieve more accurate representations is a key research focus, with methods such as the Laplacian fusion offering potential improvements. We believe that developing and improving data fusion methods could provide a better outcome. Specifically, the advancements should focus on handling large point clouds with varying accuracy and scale and address the complex geometrical holes in 3D fused models. 3D fused models, which are point cloud models, can be reconstructed into 3D models based on faces and could be developed for larger areas like 3D city models, as reported by [20], the potential applications of which include energy demand estimation, the classification of building types, and 3D cadastre. Examples of 3D models of major cities include Singapore [21], Helsinki [22], Rotterdam [23], and several Japanese cities [24].

Figure 1 illustrates the development of 3D building models. Spatial data can be obtained using several acquisition techniques, such as airborne laser scanning (ALS), terrestrial laser scanning (TLS), and drone photogrammetry. These datasets are integrated and enhanced through data fusion into 3D fused building models, and subsequently, 3D building models are reconstructed based on these fused datasets. Developing 3D representations for an urban environment results in 3D city models, including buildings, streets, and other infrastructure. These models are useful for urban applications, such as 3D cadastre and heat demand analysis for buildings. In the next five years, the development of data fusion for point cloud datasets will likely involve automated processes (to quickly and efficiently integrate big data).

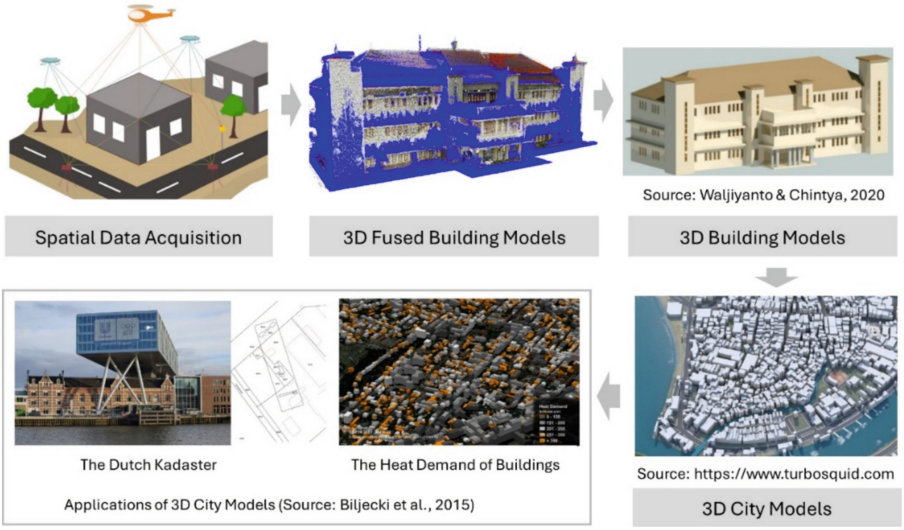

Fig. 1. Development of 3D models through data fusion.

2.2 Semantic Segmentation of 3D Models

As urban environments grow in complexity, detailed and accurate 3D city models become increasingly crucial for urban planning, GIS, and the development of smart cities. CityGML has emerged as a standard for modeling and exchanging 3D city models, encompassing various aspects such as buildings, transportation, vegetation, bodies of water, and more [25]. The semantic segmentation of building models using deep learning within the context of CityGML has opened possibilities for automating and improving certain processes. Semantic segmentation involves classifying each element of a building model into predefined categories. Efficiency and scalability are the motivation for integrating deep learning with CityGML for semantic segmentation. Traditional manual methods for segmenting building models are labor-intensive, making them challenging for large datasets. In contrast, deep learning techniques can process vast amounts of data with minimal human intervention, leading to significant time and cost savings.

Moreover, the semantic segmentation of building models is crucial for creating detailed databases of building components and structures. By automatically identifying and classifying elements such as walls, roofs, and windows, deep learning methods facilitate the creation of comprehensive semantic labels. These labels can then be converted into structured data for databases, cataloging every aspect of building assets and structural elements. This structured data is invaluable for various applications, including building management, smart city development, and geospatial analysis. Figure 2 illustrates the concept of building segmentation within CityGML to locate and generate databases of building components.

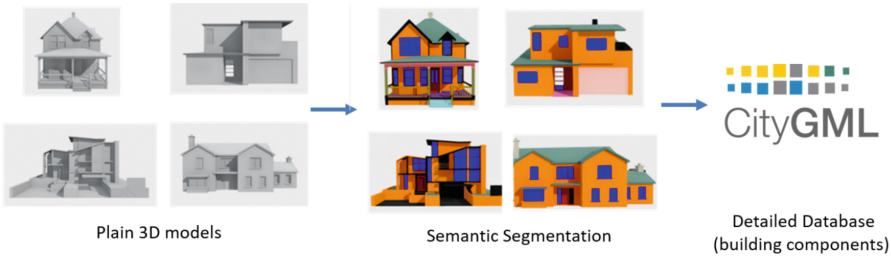

Fig. 2. The overall concept of building segmentation within CityGML.

3 The LADM

The Land Administration Domain Model (LADM) has been utilized in various countries, providing a useful structure or concept for managing land administration (LA). The flexibility of this standard allows it to be adapted for different systems worldwide and integrated with 3D spatial units. [26] stated that ISO 19152:2012 LADM serves as the official model for 3D parcel representation in the provincial city of Shenzhen in China, as well as in Finland, Malaysia, and Scotland. Additionally, approximately 35% of the countries involved in the adoption of LADM have indicated that their cadastral databases are either fully or partially based on this standard. The integration of 3D data into the LADM is a significant and ongoing development aimed at enhancing the capacity of land administration systems (LAS) to handle complex spatial information. Several countries, including the Netherlands [27], Sweden [28], Singapore [29], and Australia [30], have conducted pilot projects and implemented prototypes to test and refine these capabilities.

LADM has now been extended (i.e., LADM Edition II) to cover both land and marine environments, including information on land value and use [31]. This second edition has multiple parts with different purposes, as shown in Fig. 3. Part 1 represents LADM's generic conceptual model. Part 2 extends on LADM Edition I's land registration with a refined survey model, 3D spatial profiles, and semantically enriched code lists. Part 3 focuses on the rights, restrictions, and responsibilities (RRRs) of marine georegulation, aligning them with land concepts to provide seamless land and marine administration; this part is refined from the IHO S-121 Standards for Maritime Limits and Boundaries. Part 4 focuses on valuation information as it pertains to LA, detailing the characteristics and semantics of valuation registries that are commonly managed by government agencies. Part 5 represents the RRRs regarding spatial plan information, including land use, and Part 6 concerns the implementation of LADM (i.e., the methodology of developing country profiles and frameworks representing LA processes).

These domains are crucial for better administration, as reported by [32]. This standard is designed with flexibility, enabling the consolidation of a variety of data sources such as BIM/IFC, GIS information, property valuations, and cadastral records. As illustrated in Fig. 4, this seamless integration paves the way for versatile applications and services. In line with this trend, the integration of 3D building models with LADM appears particularly promising, especially as the number of complex buildings continues to grow. These complex scenarios require proper handling through comprehensive data models. The utilization of building information modeling (BIM) as a data source is increasingly

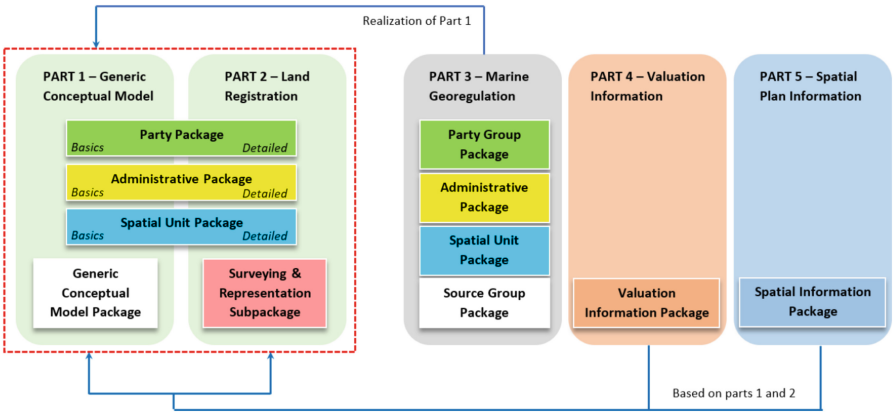

Fig. 3. The multiple parts of LADM Edition II (adopted from [32]).

attracting attention from researchers around the globe [33–36], who aim to merge it with LADM to enhance 3D land and property management. The authors of this paper are currently conducting an initiative to combine LADM Edition II with BIM for better 3D land management in Sarawak, a Malaysian state. Through such integration, authorities could enjoy a unified administration system that encompasses legal, spatial, and technical information, all of which support the development of smart city initiatives.

Table 1 (in Appendix) contains an overview of LADM implementations associated with various disciplines, including integration with BIM/IFC and CityGML, 2D and 3D underground mapping, 3D cadastre, building valuation information, RRR mapping for strata buildings, web-based applications, applied marine cadaster, and incorporating temporal elements (3D + time). It details the researchers responsible for these implementations, the year in which the research was conducted, the researchers' contributions, challenges, improvements, and recommendations from various countries that use LADM as part of their development.

Characterizing multifunctional structures is challenging, particularly where information about legal boundaries and rights, restrictions, and responsibilities (RRRs) must be identified. Apart from that, there are also challenges in integrating LADM with other standards, including CityGML, CityJSON, IndoorGML, and INTERLIS. These standards within LADM are under development and consideration by the relevant authorities. This initiative to incorporate various standards is in line with the UN's Sustainable Development Goal (SDG) 9 (industry, innovation, and infrastructure) and SDG 11 (sustainable cities and communities). By leveraging advanced models and data integration, land administration systems offer improved sustainable development and urban planning initiatives.

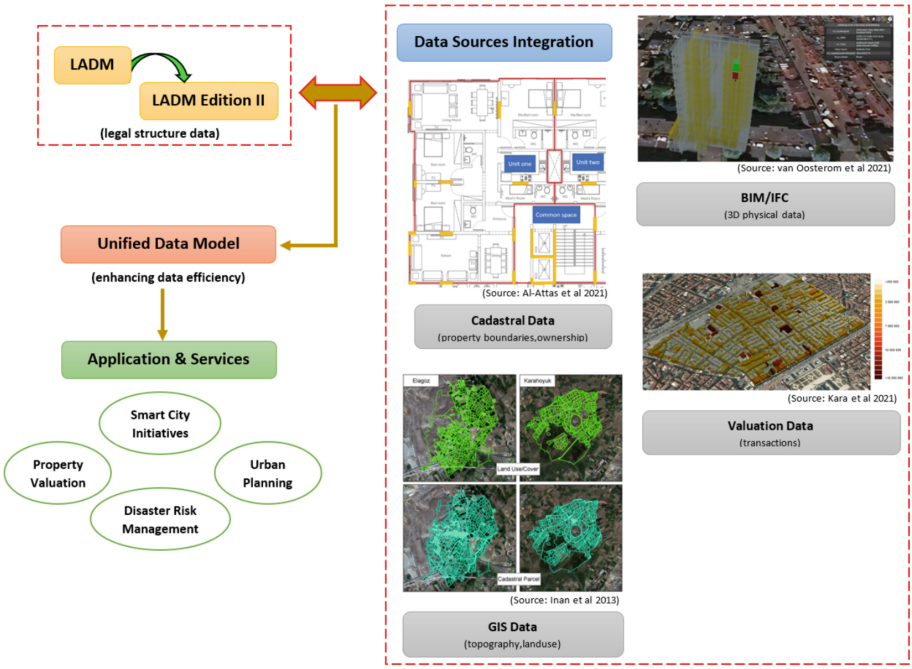

Fig. 4. Integration of data sources through the unified data model for applications and services.

4 Conclusion

This paper discussed the overall trends and development in 3D geoinformation, particularly in the disciplines of 3D GIS, 3D data fusion, semantic modeling, and LADM. Recent research has revealed that the domain is highly linked with computing, mathematics, databases, and visualization. Web and desktop computing platforms also play crucial roles in visualizing and disseminating spatial objects and information in 3D. Researchers in 3D geoinformation and the Land Administration Domain Model (LADM) have made significant advancements in techniques, processing, computing tools, algorithms, and standards. Currently, research communities are investigating better solutions and services, as seen in many major GIS vendors' advertisements and information. Above all, the 3D geoinformation domain will surely remain active, strong, and innovative.

Appendix

Table 1. Overview of LADM implementations in some countries.

Researcher(s)/Year	Contributions	Improvements	Challenges	Recommendation
Lemmen et al. (2013) [37]	The publication of land standard ISO 19152:2012 LADM provides a generic representation model which covers both spatial (main class: LA_SpatialUnit) and non-spatial aspects (main classes: LA_Party, LA_RRR, and LA_BAUnit)	A descriptive standard applicable worldwide for a variety of spatial units (e.g., land parcels, legal spaces around buildings, utilities, and networks)	Complexity in modeling and building an international consensus for refined country profiles	Selecting the relevant classes from LADM and adding country-specific attributes and associations between classes for country profile development
Trinidad & Tobago Griffth-Charles and Edwards (2014) [38]; Griffith-Charles et al. (2018) [39]	Developing a 3D LADM-based system accommodating existing legal components and extending to marine and fiscal cadastre details	The extended LADM country profile also incorporates STDM as informal value parcels	New systems can be hindered by a lack of technical development, maintenance skills, and effective user engagement	The planning database needs to be aligned with the property taxation system to ensure consistency between designated and actual land use
Poland Góźdź et al. (2014) [40]; Góźdź and van Oosterom (2016) [41]; Bydłosz (2020) [42]	Investigating the possibility of integrating CityGML for cadastral purposes by integrating the conceptual level of LADM and developing national information infrastructure	Incorporating the spatial elements of the LADM into the CityGML data model, highlighting the interrelation between these standards	Some classes (e.g., parties, administrative units, and rights) are difficult to introduce because of missing counterparts in CityGML. Lack of clear data structures defined in UML and databases	LOD2 is recommended as the most convenient level of detail. The application of solutions such as IFC, CityGML, or LandInfra in a 3D cadastre can be considered

(*continued*)

Table 1. (*continued*)

Researcher(s)/Year	Contributions	Improvements	Challenges	Recommendation
Malaysia Zulkifli et al. (2014) [43]; Rajabifard et al. (2018) [44]; Zulkifli et al. (2019) [45]; Hanafi and Hassan (2019) [46]; Zamzuri et al. (2021) [47]; Atulukwu et al. (2024) [48]; Zamzuri et al. (2024) [49]	Extending the LADM country profile with 3D representations (buildings and lots), full version management, historical information, the possibility to group multiple spatial units in one basic administrative unit with the same rights attached, and legal spaces around utilities (in 3D). Realizing LADM-based 3D cadastral registration and implementing 3D-NCDB. Further developing the country profile to encompass strata management, marine cadastre, and 4D (3D + time)	The LADM-based extensions provide a comprehensive structure for administration in Malaysia, encompassing multiple domains, including land, strata buildings, marine, and indigenous RRRs	Lacking available data causes difficulties in realizing real-world situations and ensuring data compatibility and seamless integration without data loss or inconsistencies	Need for coordination among agencies for effective implementation

(*continued*)

Table 1. (*continued*)

Researcher(s)/Year	Contributions	Improvements	Challenges	Recommendation
The Netherlands Kara et al. (2019) [50]; Hagemans et al. (2022) [51]	One of the earliest initiatives to implement LADM into land administration to extend the country profile with 3D cadastre and valuation information. Newly surveyed cadastral boundary geometry is documented by applying a sub-package (Survey and Representation) for a solid solution to the process	Developed and implemented advanced technologies to support LADM, such as integrating LADM with 3D cadastre systems and CityGML	Ensuring high-quality and consistent data across different regions and systems	Continue to invest in technological advancements that can enhance the capabilities of LADM, such as incorporating AI and machine learning for data analysis and decision-making. Promote the use of cloud-based solutions for data sharing among stakeholders
Cyprus Elia et al. (2011) [52]; Demetriades et al. (2023) [53]	Proposed a valuation model and demonstrated how BIM can enhance the valuation process by comprehensively representing land characteristics in a 3D environment. Showed the potential for BIM to streamline valuation processes and improve compliance with industry regulations	Future capability to represent legal spaces related to apartments or utility infrastructures as 3D spatial units	The non-one-to-one correspondence between the existing valuation model requires adjustments. The absence of certain attributes in ISO 19152-4 that are present in Cyprus's existing valuation model necessitates creative modeling solutions	The establishment of a database for the proposed valuation model in alignment with ISO 19152-4. The development of 3D visualization of the model to support land value queries and present results visually. The bidirectional exchange of data between the IFC model and the database to automate valuation processes

References

1. Burrough, P.A.: Principles of Geographical Information Systems for Land Resources Assessment (Monographs on Soil and Resources Survey No. 12). Oxford University Press, Oxford, UK (1986)
2. Rahman, A.A.: The 3D geoinfo journey from 2006 to 2022—a reflection. In: Kolbe, T.H., Donaubauer, A., Beil, C. (eds.) Recent Advances in 3D Geoinformation Science. 3DGeoInfo 2023. Lecture Notes in Geoinformation and Cartography, pp. 853–861. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-43699-4_51
3. Molenaar, M.: An Introduction to the Theory of Spatial Object Modelling for GIS. Taylor & Francis, Milton Park (1998)
4. Zlatanova, S., Rahman, A.A., Shi, W.Z.: Topological models and frameworks for 3D spatial objects. Comput. Geosci. **30**(4), 419–428 (2004). https://doi.org/10.1016/j.cageo.2003.06.004
5. Azri, S., Ujang, U., Castro, F.A., Abdul-Rahman, A., Mioc, D.: Classified and clustered data constellation: An efficient approach of 3D urban data management. ISPRS J. Photogramm. Remote. Sens. **113**, 30–42 (2016)
6. Rashidan, H., Musliman, I.A., Sani, M.J., Abdul Rahman, A.: Semantic labeling of 3D buildings by using graph neural network (GNN). Int. Arch. Photogramm. Remote. Sens. Spat. Inf. Sci. **48**, 307–311 (2024). https://doi.org/10.5194/isprs-archives-XLVIII-4-W9-2024-307-2024
7. Mutiarasari, W.M., Rahman, M.Z.A., Rahman, A.A.: Investigating data fusion from three different point cloud datasets using iterative closest point (ICP) registration. In: Kolbe, T.H., Donaubauer, A., Beil, C. (eds.) Recent Advances in 3D Geoinformation Science. 3DGeoInfo 2023. Lecture Notes in Geoinformation and Cartography, pp. 299–308. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-43699-4_18
8. Maset, E., Valente, R., Iamoni, M., Haider, M., Fusiello, A.: Integration of photogrammetry and portable mobile mapping technology for 3D modeling of cultural heritage sites: The case study of the Bziza Temple. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **XLIII-B2**, 831–837 (2022). https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-831-2022
9. Li, S., Ge, X., Hu, H., Zhu, Q.: Laplacian fusion approach of multi-source point clouds for detail enhancement. ISPRS J. Photogramm. Remote. Sens. **171**, 385–396 (2021). https://doi.org/10.1016/j.isprsjprs.2020.11.021
10. Kara, A., van Oosterom, P., Lemmen, C., Kalogianni, E.: Design of the new structure and capabilities of LADM edition II including 3D aspects. Land Use Pol., **137**, 107003 (2024). https://doi.org/10.1016/j.landusepol.2023.107003
11. Zamzuri, A., Abdul-Rahman, A., Hassan, M. I., van Oosterom, P.: 3D land administration system for Wilayah Sarawak based on LADM edition II—preliminary works. In: van Oosterom, P., Paasch, J. M. (eds.) 11th International FIG Land Administration Domain Model/3D Land Administration Workshop, pp. 149–166 (2023). https://doi.org/10.4233/uuid:b617293f-e902-4c08-ba93-b72aff2ee30d
12. Guler, D.: Implementation of 3D spatial planning through the integration of the standards. Trans. GIS **27**(8), 2252–2277 (2023). https://doi.org/10.1111/tgis.13122
13. Abdul-Rahman, A.: The design and implementation of a two and three-dimensional triangular irregular network based GIS. PhD Thesis. University of Glasgow, UK (2000). https://theses.gla.ac.uk/4069/
14. Zlatanova, S.: 3D GIS for urban development. PhD Thesis. ITC The Netherlands & Technical University of Graz, Austria (2000). https://zlatanova.xyz/PhDthesis/
15. Pilouk, M.: Integrated modelling for 3D GIS. PhD Thesis. Wageningen Agricultural University and ITC (1996). https://edepot.wur.nl/210498