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Using a 3D city model for monitoring flash flood risks in Salalah (Oman)

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ABSTRACT

The paper investigates the issues and challenges to use a 3D city model for monitoring flash flood risks in Salalah (Oman) by using the Geography Markup Language (CityGML) standards version 2.0. In fact, 2D and 2.5D GIS solutions cannot analyse flood complex problems inside the urban area. Hence, the study seeks to reduce time and effort for the decision-makers by proposing a 3D city model for flood risk management. The study has used geospatial tools and databases such as ArcGIS, Watershed Modeling System (WMS), FME, PostgreSQL-PostGIS, and 3D City Database (3DCityDB) to generate the 3D model and to test the capability of establishing unified geospatial data structure including 3D city objects, hydrology data, and geological data. The findings show the importance of addressing flood risks data and arranging it in the 3D geodatabase. The findings also show that establishing a 3D city model based on CityGML standard requires homogenized definitions and standards for city objects (surface and subsurface) and hydrology data. Besides, it needs to address the issues and challenges in the level of the data structure. Based on the results, the researchers will further study the solutions to integrate the 3D city model and natural hazards management applications in Oman.

1. INTRODUCTION

Oman has coasts that have a length of 3165 kilometers located towards the Indian Ocean where tropical storms occur. Therefore, it experiences frequent climatic events such as tropical depression and cyclone (Al-Kalbani, 2011; Dube et al., 2020). In addition to that, the low parts of the coastal areas can be exposed to coastal floods caused due to high waves that come along with the climactic event. Moreover, these climatic events affect humans' lives and cause damage to city infrastructure, which costs millions of dollars. Salalah is one of the south Omani cities that has faced several climatic events such as cyclone Mekunu in 2018 and tropical depression from 27 May to 1 June 2020, as shown in Fig. 1.

The impact of these events has led to the importance of evaluating Salalah city infrastructure by using the 3D geospatial data approach to test the extent to which the Salalah city infrastructure matches with the hydrological system in that area. This study, thus, investigates the issues and challenges of implementing a 3D city model to monitor, evaluate and manage these dangers based on developing a small-scale 3D city model using CityGML standard version 2.0.

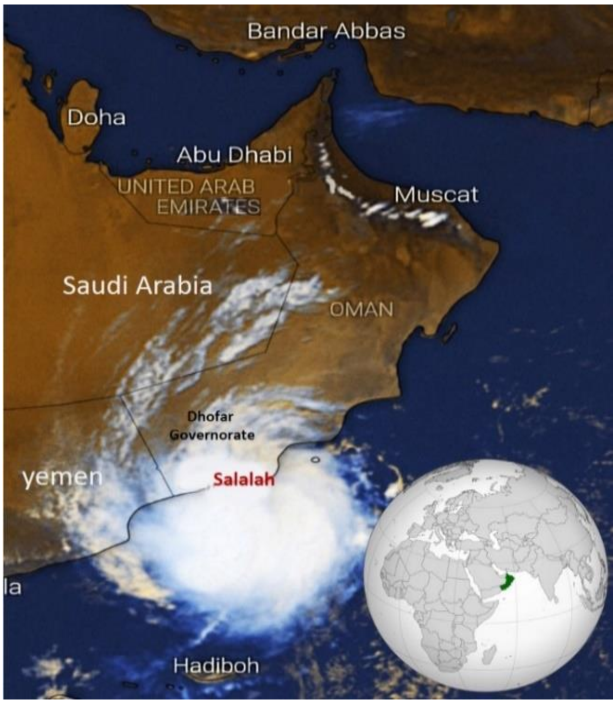

Figure 1. The tropical depression, 30 May 2020

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Monitoring and assessing flash floods and managing mitigation measures is a complex project that requires great effort and a relatively long period of time. The study seeks to reduce time and effort by employing a 3D city model, which mainly depends on the design of the 3D city model databases to manage the influence of flood risk on the city infrastructure (surface and sub-surfaces spatial objects). Bee et al., (2008), Ruíz (2015) and Tymkow et al., (2016) show that a mechanism could be established to deal with flood risk data by linking geospatial data and identifying effective models, analyzing appropriate simulation, estimation techniques, and designing a flood intensity scale. On the other hand, The Bureau for Crisis Prevention and Recovery (BCPR) in its 2004 international report indicated that more efforts should be made to collect disaster-related data, as well as pointing out, in its recommendations, to the need to support the national risk instrument to fund the production of information needed for decision-making at a national level (UNDP, 2004).

Nowadays, the infrastructure, such as multi-floor buildings and underground utilities, indoor and outdoor spatial objects in the urban areas is complicated as it requires using 3D geodata sets and 3D geospatial platforms with high performance. Additionally, employing the current geospatial solutions may not be useful to analyze and visualize complex problems, so there is an urgent need to develop 3D city model based on interoperability solutions (Biljecki et al., 2015b; Stoter et al., 2014, 2010). 3D geospatial platforms, 3D database and their related applications are considered as good initiatives for representing the 3D spatial objects and entire cities. The capability of these geospatial technologies has some solution to analyse complex data structure issues (Abdul Rahman et al., 2019; Siew and Kumar, 2019; Yao et al., 2018). Hence, efforts to make the 3D city model successful for flood risk management requires a homogenous and stable environment for all the models and standards such as hydrology, meteorology, geomorphology, geology, hydrogeology, CityGML, BIM /IFC and Shapefile.

A number of countries around the world have applied the GIS for flood risk management, while other countries are working toward 3D GIS by using their standard, data format and database (Al-Kalbani, 2011; Ruíz, 2015). At this point, the 3D geospatial institutions and researchers have made an effort to develop a framework for flood modeling based on using the OGC CityGML standard, CityJSON and others. Nevertheless, the pre-implementation has exposed several issues and challenges that need to be addressed in the level of data processing, data integration, data modeling, data converting, and data visualizing (Al Kalbani and Abdul Rahman, 2019; Kumar et al., 2018; Zlatanova et al., 2014). Part of the challenges is related to DEM sources' efficiency in 3D flood modeling and complex hydraulic simulation. In this context, Bakuła et al., (2016) and Li and Wong (2010) investigated how hydraulic modeling and application can be influenced by the source of different elevation data. While, Muhadi et al., (2020) discussed the use of Digital Elevation Model (DEM) that extruded from LiDAR for flood applications.

Establishing a flood risk database within the 3D city model is a complex task at the national level. On the one hand, dealing with 3D city model requires new solutions for integrating the data structure for both the surface and subsurface spatial objects (Al Kalbani and Abdul Rahman, 2019), where, most of the 3D geospatial initiatives focus on surface spatial objects data structure with less interest to model subsurface spatial objects. On the other hand, there is a need to find an approach that bridges between different available 3D geospatial standards in terms of geometric and semantics information to supports the interoperability between DBMSs, services, and stakeholders (Stoter et al., 2010).

This paper is arranged in eight Sections, where the Second section discusses the study area. Then, Section three reviews the CityGML standard. While Section four reviews the current state of Oman geospatial data and SDI, the methodology is explained in Section five. The sixth Section includes the discussion and outcomes of the study. The benefit of implementing 3D city model for flood risk management is summarized in Section seventh and the eighth Section ends with the conclusion.

2. STUDY AREA

Salalah is one of the main cities in the Dhofar Governorate (southwest of the Sultanate of Oman) (Zerboni et al., 2020). The population of the governorate is more than 450,000, distributed between the coastal plain and mountainous and desert areas (NCSI, 2020). The urban area in Salalah is spread on a narrow coastal plain where it is located between mountains, that are more than 1700 meters high (see Fig. 2), and coastal line and passing throughout it are a number of wadis and alluvial fans.

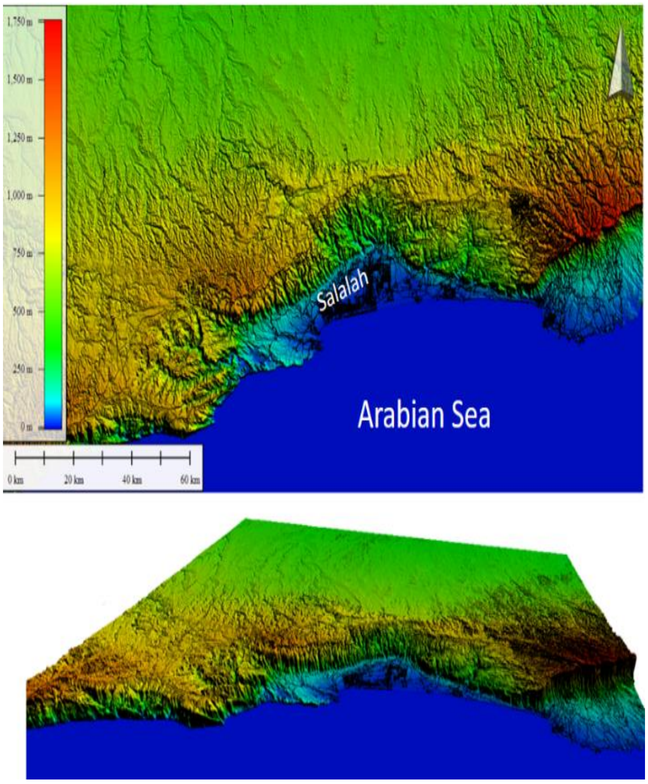

Figure 2. Salalah Digital Elevation Model (DEM)

The coastal plain can reach 13 km in its maximum width. The Dhofar mountain range was formed by the tectonic fault and uplift movement. Most of the rocky structure scattered in this region is dominated by solid limestone.

Moreover, Dhofar is considered a semi-arid area with approximately 100 – 400 mm of rainfall per year (Zerboni et al., 2020). Also, this area has a monsoon from July to August, in which the weather becomes cloudy with little rain. This area can also be affected by cyclones and tropical depressions. One of the clime events Dhofar had experienced is the tropical depression (27 May to 1 June 2020) which caused heavy rains so much so that some of the Dhofar districts received more than 1000 mm in 5 days. Salalah (study area) received 531 mm, causing flash floods and destroying some city infrastructure (Mrmwroman, 2020).

Rapid development in Salalah played a role in natural phenomena such as floods becoming as challenges. Moreover, the accelerated pressure on urban spatial holdings contributed to the exploitation of flood-prone areas, and in most of this exploitation was not accompanied by providing the infrastructure of water drainage (Al-Kalbani, 2011). The Crisis and Recovery Office has indicated in its global report to UNDP 2004 that "it does not necessarily mean that the urban transformation increases flood risk and can actually reduce it if it is well managed" (UNDP, 2004). However, the damage caused by floods cannot always be the main natural factor for exacerbating events. Instead, it is often the human factor that provides the right environment for these risks to develop into disasters.

Moreover, the high cost for constructing and maintaining the flood protection infrastructure was constrained integration of flood risk measures into urban planning efforts effectively. In fact, establishing flood risk infrastructure at the government level can be affected by two elements, which are the economic feasibility and practical feasibility, and often the economic factor is the dominant factor in addition to the amount of available budget (Al-Kalbani, 2011). In all scenarios, when planning deviates from the inclusion of flood risk as a priority, this uncontrolled planning may cause challenges in normal rainfall and make matters worse in the case of heavy rains.

3. CityGML STANDARD

CityGML is an open XML file format for exchanging, storing, and representing 3D objects. Moreover, the CityGML initiatives have been developed by the Special Interest Group3D (3D SIG), and it is organized now by Open Geospatial Consortium (OGC). CityGML standard has been adopted as an international standard for exchanging the format of 3D geospatial objects and the 3D city model based on the XML file format and the GML 3xx. Besides, CityGML (version 2.0) includes 13 models to store the spatial objects and five levels of detail (LoD) (Biljecki, 2017; Biljecki et al., 2015b; Stouffs et al., 2018).

CityGML presents the most common natural and human spatial features that can be found in the cities and their surroundings by determining their geometric and semantic information (Arroyo Ohori et al., 2018; Biljecki, 2017; Biljecki et al., 2017, 2015a, 2015b; Kensek, 2014; Stoter et al., 2016). Furthermore, the structure of CityGML file format is developed based on a hierarchy structure both for geometric and semantic information. Now, there are various spatial applications for CityGML standard such as solar potential estimation, flood risk assessment and noise monitoring. (Biljecki, 2017; Biljecki et al., 2015b; Preka and Doulamis, 2016; Soon et al., 2016; Yao et al., 2018).

4. THE CURRENT STATE OF OMAN GEOSPATIAL DATA AND SDI

Oman government established its national SDI in 2014 to standardize the geospatial activities and business at the national level. Since then, the geospatial workflow of Oman NSDI and its partners (Oman GIS stakeholders) are limited to the 2D and 2.5D geospatial data (Al Kalbani et al., 2018; Das et al., 2017; NCSI, 2017a, 2017b). In fact, Oman is one of the developed countries which has a complex city infrastructure. As a result, using 2D and 2.5D geospatial data may not be efficient in analysing flood risk inside the big cities and complex structures. Hence, the decision-makers in Omani municipalities need GIS solutions based on utilizing a 3D city model.

5. METHODOLOGY

The study created a small-scale 3D city model for Salalah district by using CityGML version 2.0 and spatial data collected from the related geospatial agencies in Oman (2D, 2.5D geospatial data). Geospatial tools such as FME engine was used to generate 3D spatial objects for surface and subsurface spatial objects based on using CityGML standard version 2.0 and also for exchanging the file format from one model to the others. Besides, databases PostgreSQL-PostGIS and 3DCityDB were used to register and store the 3D models for surface and subsurface objects in a relational database.

The study created a building model at CityGML LoD1 by extruding the building footprint using the high value from the file attributes. Also, LoD1 was used to create the terrain model. Since the CityGML 2.0 does not fully support the subsurface spatial objects and models, the study used the CityGML generic module to develop some of these subsurface models such as geological model and pipeline networks.

The study used ArcGIS (hydrology tools), the Watershed Modeling System (WMS) to extract wadi (stream) networks and watershed using ASTER DEM with a resolution of 30 meters. Besides, WMS applications were used to produce flood spread layers based on digital terrain data and floodwater estimative elevation values between 1 – 3 meters.

On the one hand, the study has carried some experiments to investigate further the issues and challenges for constructing a unified 3D data structure based on the use of CityGML standard version 2.0 for surface and subsurface spatial objects. On the other hand, the study has explored the integration challenges between geological models, hydrological models and 3D city models.

The study has investigated how to integrate the benefits of satellite images and 3D city models for flood risk management. Satellite images (Sentinel-2) with a resolution of 10 meters for the tropical depression from 1-3 June 2020 were obtained from https://eos.com/landviewer, and analysed using change detection methods. The role of satellite images in this study is to draw a map of the flood spread in the study area by overlapping the 3D models (road and building) in the 3D city model with 2D satellite images that are classified using change detection. In addition, this step contributed to tracking and highlighting some of the flooding problems related to the failure of drainage networks along highways and inside cities.

Since there is no professional 3D viewer to visualize both surface and subsurface spatial objects, the study has used several visualizing tools such as FME Data Inspector, Google Earth, FZK viewer and Cesium.

6. DISCUSSION AND RESULTS

The study has created a small-scale 3D city model for most surface city spatial objects in LoD 1 (see Fig. 3), but it faced a challenge to go higher to LoD 3 and LoD 4 due to missing rich data such as BIM/IFC. Also, the study has been able to generate wadi (stream) networks and watershed using Salalah digital terrain data.

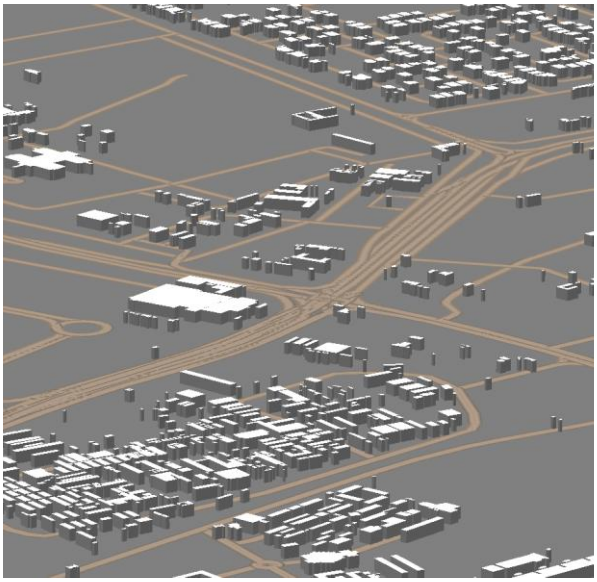

Figure 3. Small-scale 3D city model for Salalah

The real challenge in developing the 3D city model was how to create subsurface spatial objects, in which CityGML version 2.0 does not provide a definition to support subsurface objects except for the CityGML Application Domain Extension (ADE) for utility network. Thus, the study created some of the subsurface spatial objects in LoD1 using the CityGML generic module. However, there are some challenges related to semantic, geomatic and topology that need to be addressed to enhance 3D subsurface models. Other challenges are related to 3D spatial analysis and the process of creating a unified relational database for surface and subsurface spatial objects.

Since the CityGML version 2.0 does not include hydrological models and flooding simulation, the study used several applications separately and outcomes were linked to one 3D city model. During this stage, the experiments showed that the 3D city model is able to determine the areas that might be subject to water flooding by linking the 3D city model, terrain and flood layer exported from WMS, as shown in Fig. 4.

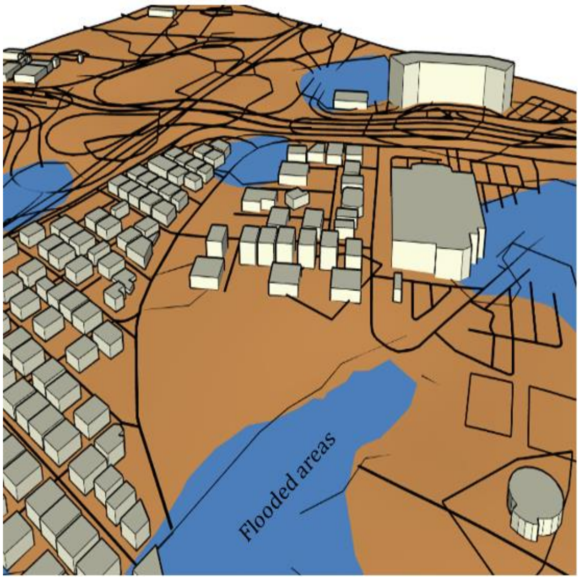

Figure 4. Areas subject to flooding

Another advantage of managing flood data in 3D city model is providing the capability to determine the level to which floodwater can reach in each of the city buildings. Nevertheless, there is still a challenge in registering the value to which floodwater can reach automatically in the database for each of the building faces and edges due to the complexity of CityGML data structure in terms of systematic and geometric information.

Moreover, the experiments demonstrated that there is a possibility to integrate the analysis of satellite images using change detection methods and 3D city models to map the distribution of internal floods in residential areas and to highlight some issues in the city infrastructure. Based on this approach, the results revealed that floodwater collects on the sides of highways and some modern bridges. Also, it revealed that floodwater was collecting in residential areas. This is due to many reasons, and the most important ones are lack of water drainage networks, failure of drainage channels, due to the accumulation of impurities coming from the watershed, the incompatibility of the engineering design of the drainage channels and the volume of water flow. There are other challenges due to low level of the ground surface in some residential areas and weak water infiltration into the ground.

Research is still ongoing to address the issues listed below:

- Defining the water stream paths inside the city in the absence of Light Detection and Ranging (LiDAR) data, which is a restricted data in Oman and needs several official permissions.

- Integrating CityGML and the current mathematic hydrological models in a unified ADE, data structure and 3D geodatabase.
- Designing equations that are suitable for estimating the peak of the floods considering Salalah environment, climate, the nature of urban patterns and characteristics of dams and their ability to drain water. Therefore, creating hydrodynamic modeling of flood flows using CityGML standard needs to determine the relation with other factors such as the surface of the wadi, slope, velocity, leakage rate to the underground, evaporation, and 3D objects resistance.
- Upgrading 3DCityDB data structure to import subsurface spatial objects.
- Developing homogenized definitions within CityGML standard to manage relationships between different subsurface spatial objects, geological models and hydrological models.
- Developing a new logarithm of hydrodynamic modeling of flood flows based on CityGML standard and 3D raster map (voxel).
- Calculating the water drainage that comes from the city's infrastructure, where the roofs of buildings and paved areas contribute to the gathering of rainwater in residential areas and low areas.
- Designing a mechanism to predict urban infrastructure behavior during the flooding, where the failure of bridges, roads and drainage channels can shut down the natural paths of valleys and change the direction of their flow, causing internal flooding in residential areas.
- Integrating indoor and outdoor navigation and flood risk management.
- Updating the hydrology simulation results automatically into the databases at the level of CityGML schema(s) and LoD(s).
- Examining the performance of the JavaScript Object Notation (JSON) and CityJSON datasets as alternative solutions to create a flood spatial data structure in the 3D city model.

Other challenges are related to CRS/SRID, quality of data structures, geomatics representation, the problem of semantic cording, creating the data structure in terms of schema(s) and LoD(s), integration with the DEM, the topology issues, data retrieval, data size, data index, 3D spatial analysis, spatial operations and rendering over Cesium.

7. THE BENEFIT OF IMPLEMENTING 3D CITY MODEL FOR FLOOD RISK MANAGEMENT

The expected benefits of using 3D city model for flood risk management study are summarized below:

- A suitable environment for the modeling of floods and their impact on the urban areas in 3D
- The ability to test infrastructure projects before implementation on the ground
- A suitable environment for flood risk management and rescue operations

8. CONCLUSION

This paper attempts to investigate the challenges of using a 3D city model for monitoring flood risks in Salalah. The outcomes of the study show that a 3D city model based on CityGML still needs to address some issues and challenges related to the efficiency of this standard for hydrological analysis and for managing surface and subsurface spatial objects in the unified data structure.

The study results also demonstrated that 3D geospatial data is more efficient in solving planning problems and defining the issues that may increase flood risks. This, in turn, it helps to understand and assess the nature of risks and design clear vision to manage rescue efforts. This research is still a work-in-progress and the authors believe that the initial outcomes of this paper can highlight the importance of including 3D geospatial solutions for flood risk management in Oman.

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REFERENCES

Abdul Rahman, A., Rashidan, H., Musliman, I.A., Buyuksalih, G., Bayburt, S., Baskaraca, P., 2019. 3D Geospatial Database Schema for Istanbul 3D City Model. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLII-4/W16, 11–16. https://doi.org/10.5194/isprs-archives-XLII-4-W16-11-2019

Al-Kalbani, K., 2011. Monitoring and Assessing Flood Risks & Maintaining the Procedures to Limit their Danger using Geographical Information Systems, Remote Sensing and Hydrological Modeling (Case Study :Al-Seeb Willayat) ". Sultan Qaboos University.

Al Kalbani, K., Abdul Rahman, A., 2019. Integration Between Surface and Subsurface Spatial Objects for Developing Oman 3D SDI Based on the CityGML Standard. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLII-4/W16, 79–84. https://doi.org/10.5194/isprs-archives-XLII-4-W16-79-2019

Al Kalbani, K., Abdul Rahman, A., Al Awadhi, T., Alshannaq, F., 2018. Development Of A Framework for Implementing 3D Spatial Data Infrastructure In Oman – Issues And Challenges. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLII-4/W9, 243–246. https://doi.org/10.5194/isprs-archives-XLII-4-W9-243-2018

Arroyo Ohori, K., Biljecki, F., Kumar, K., Ledoux, H., Stoter, J., 2018. Modeling Cities and Landscapes in 3D with CityGML, in: Building Information Modeling. Springer International Publishing, Cham, pp. 199–215. https://doi.org/10.1007/978-3-319-92862-3_11

Bakuła, K., StĘpnik, M., Kurczyński, Z., 2016. Influence of

Elevation Data Source on 2D Hydraulic Modelling. Acta Geophys. 64, 1176–1192. https://doi.org/10.1515/acgeo-2016-0030

Bee, M., Benedetti, R., Espa, G., 2008. Spatial Models for Flood Risk Assessment. Environmetrics 19, 725–741. https://doi.org/10.1002/env.932

Biljecki, F., Ledoux, H., Stoter, J., 2017. Generating 3D City Models Without Elevation Data. Comput. Environ. Urban Syst. 64, 1–18. https://doi.org/10.1016/j.compenvurbsys.2017.01.001

Biljecki, F., Ledoux, H., Stoter, J., 2015a. Improving the Consistency of Multi-LoD CityGML Datasets by Removing Redundancy. pp. 1–17. https://doi.org/10.1007/978-3-319-12181-9_1

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., Çöltekin, A., 2015b. Applications of 3D City Models: State of the Art Review. ISPRS Int. J. Geo-Information 4, 2842–2889. https://doi.org/10.3390/ijgi4042842

Biljecki, F., 2017. Level of Details in 3D City Models,Published PhD Thesis. Delft University of Technology. https://doi.org/10.4233/uuid:f12931b7-5113-47ef-bfd4-688aae3be248

Das, A., Chandel, K., Narain, A., 2017. Value of Geospatial Technology in Boosting Omans Economy, in: Oman Geospatial Forum 2017. Oman National Survey Authority, Muscat, pp. 1–74.

Dube, A., Ashrit, R., Kumar, S., Mamgain, A., 2020. Improvements in Tropical Cyclone Forecasting through Ensemble Prediction System at NCMRWF in India. Trop. Cyclone Res. Rev. https://doi.org/10.1016/j.tcrr.2020.04.003

Kensek, K.M., 2014. Building Information Modeling. Build. Inf. Model. 1–285. https://doi.org/10.4324/9781315797076

Kumar, K., Ledoux, H., Stoter, J., 2018. Dynamic 3D Visualization of Floods: Case of the Netherlands. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLII-4/W10, 83–87. https://doi.org/10.5194/isprs-archives-XLII-4-W10-83-2018

Li, J., Wong, D.W.S., 2010. Effects of DEM Sources on Hydrologic Applications. Comput. Environ. Urban Syst. 34, 251–261. https://doi.org/10.1016/j.compenvurbsys.2009.11.002

Mrmwroman, 2020. Precipitation Report from 27 May to 1 June, Mrmwroman Report.

NCSI, 2020. Monthly Statistical Bulletin,June 2020, Monthly Statistical Bulletin. https://doi.org/10.36548/jsws.2020.2

NCSI, 2017a. Oman National Spatial Data Infrastructure Strategy V5.0. National Center for Statistics and Information, Oman.

NCSI, 2017b. Oman National Spatial Data Infrastructure, 1st ed. National Center for Statistics and Information, Oman.

Muhadi, N.A., Abdullah, A.F., Bejo, S.K., Mahadi, M.R., Mijic, A., 2020. The Use of LiDAR-Derived DEM in Flood Applications: A Review. Remote Sens. 12, 2308. https://doi.org/10.3390/rs12142308

Preka, D., Doulamis, A., 2016. 3D Building Modeling in LoD2 Using the CityGML Standard. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLII-2/W2, 11–16. https://doi.org/10.5194/isprs-archives-XLII-2-W2-11-2016

Ruíz, A.A.B., 2015. An Urban Flooding Simulation Technique by Using 3D City Information Model 3, 54–67.

Siew, C., Kumar, P., 2019. CitySAC: A Query-Able CityGML Compression System. Smart Cities 2, 106–117. https://doi.org/10.3390/smartcities2010008

Soon, K.H., Tan, D., Khoo, V., Soon, K.H., Tan, D., Khoo, V., 2016. Initial Design to Develop a Cadastral System that Supports Digital Cadastre, 3D and Provenance for Singapore, in: 5th International Workshop on 3D Cadastres. pp. 419–432.

Stoter, J., Brink, L. Van Den, Vosselman, G., Goos, J., Verbree, E., Klooster, R., Berlo, L. Van, Vestjens, G., Reuvers, M., Thorn, S., 2010. A Generic Approach for 3D SDI in the Netherlands. Lect. Notes Comput. Sci. 1–22.

Stoter, J., Ploeger, H., Roes, R., Riet, E. Van Der, Biljecki, F., Stoter, J., Ploeger, H., Roes, R., Riet, E. Van Der, Biljecki, F., 2016. First 3D Cadastral Registration of Multi-level Ownerships Rights in the Netherlands, in: 5th International Workshop on 3D Cadastres. pp. 491–504.

Stoter, J., Vosselman, G., Dahmen, C., Oude Elberink, S., Ledoux, H., 2014. CityGML Implementation Specifications for a Countrywide 3D Data Set. Photogramm. Eng. Remote Sens. 80, 1069–1077. https://doi.org/10.14358/pers.80.11.1069

Stouffs, R., Tauscher, H., Biljecki, F., 2018. Achieving Complete and Near-Lossless Conversion from IFC to CityGML. ISPRS Int. J. Geo-Information 7, 355. https://doi.org/10.3390/ijgi7090355

Tymkow, P., Karpina, M., Borkowski, A., 2016. 3D GIS for Flood Modelling in River Valleys. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLI-B8, 175–178. https://doi.org/10.5194/isprsarchives-XLI-B8-175-2016

UNDP, 2004. Bureau for Crisis Prevention and Recovery (Bcpr) 2004 Report : Thematic Trust Fund for Crisis Prevention and Recovery United Nations Development Programme. Bur. Cris. Prev. Recover.

Yao, Z., Nagel, C., Kunde, F., Hudra, G., Willkomm, P., Donaubauer, A., Adolphi, T., Kolbe, T.H., 2018. 3DCityDB - a 3D Geodatabase Solution for the Management, Analysis, and Visualization of Semantic 3D City Models Based on CityGML. Open Geospatial Data, Softw. Stand. 3. https://doi.org/10.1186/s40965-018-0046-7

Zerboni, A., Perego, A., Mariani, G.S., Brandolini, F., Al Kindi, M., Regattieri, E., Zanchetta, G., Borgi, F., Charpentier, V., Cremaschi, M., 2020. Geomorphology of the Gebel Qara and Coastal Plain of Salalah (Dhofar, Southern Sultanate of Oman). J. Maps 16, 187–198. https://doi.org/10.1080/17445647.2019.1708488

Zlatanova, S., Ghawana, T., Kaur, A., Neuvel, J.M.M., 2014. Integrated Flood Disaster Management and Spatial Information: Case Studies of Netherlands and India. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XL–8, 147–154. https://doi.org/10.5194/isprsarchives-XL-8-147-2014