Development and Usability Testing of the Participatory Urban Plan Monitoring Prototype for Indonesian Smart Cities Based on Digital Triplets

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Key words: urban plan monitoring, digital triplets, 3D RRRs, participatory approach, LADM, smart city, Spatial Data Infrastructure

SUMMARY

Sustainable Development Goals (SDGs) prescribed justice, strong institutions, and partnerships to encourage citizens' participation and inclusion. Goal 11 addresses urban areas: "Make cities and human settlements inclusive, safe, resilient and sustainable." The SDGs are impossible to realize without the involvement of cities and municipalities. They must align their land-use plans to align to SDG indicators and measure their progress collaboratively. Therefore, developing an application for participative monitoring of the implementation of urban plans is crucial to detect challenges and evaluate alternative scenarios for intervention-making, achieving SDGs' targets and indicators. On the other hand, investments or disruption in a city, either physical or non-physical forms, should change the configuration of Rights, Restrictions, and Responsibilities (RRRs) on a land parcel or 3D space. Therefore, monitoring the implementation of the urban plan is required to gauge a city's progress towards fulfilling SDGs indicators. In the digital transformation and democracy era, cities may benefit from Geo-ICT to improve their capability to manage land information and establish spatially enabled societies to fulfill land management roles. The developments of application for Participatory Urban Plan Monitoring (PUPM) presented in this article uses the proposed Spatial Plan Information Package within ISO 19152:2012 on the Land Administration Domain Model (LADM) revision. LADM is used to construct a 3D representation of restrictions and responsibilities from land-use (urban) planning. This article presents the development of a web-based application for PUPM with emphasis on the use of Digital Triplets by adding legal spaces to Digital Twin. In supporting the PUPM of a city, the two-way information flows are between authorities and local citizens can be an updating system. An initial usability test is conducted in order to improve PUPM further. From the usability test conducted, this study found the potential of a two-way 3D spatial information flow to support PUPM.

SUMMARY (Bahasa Indonesia)

Tujuan Pembangunan Berkelanjutan (SDGs) menetapkan keadilan, lembaga yang kuat, dan kemitraan untuk mendorong partisipasi dan inklusi warga negara. Sasaran 11 dari SDG membahas wilayah perkotaan: "Menjadikan kota dan pemukiman manusia inklusif, aman, tangguh, dan berkelanjutan." SDGs tidak mungkin terwujud tanpa keterlibatan kota. Mereka harus menyelaraskan rencana penataan ruang mereka dengan indikator SDG dan mengukur kemajuan mereka secara kolaboratif. Oleh karena itu, mengembangkan aplikasi pemantauan partisipatif dari pelaksanaan rencana perkotaan sangat penting untuk mendeteksi tantangan dan mengevaluasi skenario alternatif untuk pembuatan intervensi, untuk mencapai target dan indikator SDGs. Di sisi lain, investasi dan intervensi dapat menjadi gangguan di suatu kota, baik dalam bentuk fisik maupun non fisi, serta mengubah konfigurasi Hak, Pembatasan, dan Tanggung Jawab (RRR) pada sebidang tanah atau ruang 3D. Oleh karena itu, pemantauan pelaksanaan rencana kota diperlukan untuk mengukur kemajuan kota dalam memenuhi indikator SDGs. Dalam era transformasi digital dan demokrasi, kota-kota dapat memanfaatkan Geo-ICT untuk meningkatkan kemampuan mereka dalam mengelola informasi pertanahan dan membentuk masyarakat yang mampu secara spasial untuk memenuhi peran pengelolaan lahan. Perkembangan aplikasi Pemantauan Rencana Kota Partisipatif (PUPM) yang disajikan dalam artikel ini menggunakan Paket Informasi Rencana Tata Ruang yang diusulkan dalam ISO 19152: 2012 tentang revisi Land Administration Domain Model (LADM). LADM digunakan untuk membangun representasi 3D dari batasan dan tanggung jawab dari perencanaan penggunaan lahan (perkotaan). Artikel ini menyajikan pengembangan aplikasi berbasis web untuk PUPM dengan penekanan pada penggunaan Digital Triplet dengan menambahkan ruang hukum pada Digital Twin. Dalam mendukung PUPM suatu kota, arus informasi dua arah antara otoritas dan warga setempat dapat menjadi suatu sistem pemutakhiran. Uji kegunaan awal dilakukan untuk meningkatkan PUPM lebih lanjut. Dari uji usability yang dilakukan, penelitian ini menemukan potensi aliran informasi spasial 3D dua arah untuk mendukung PUPM.

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1. INTRODUCTION

The need for monitoring the implementation of the urban plan has never been more critical. Murata (2004) demonstrates multidimensional representation for urban planning processes, mainly to compare the actual urban objects and urban plan. LeGates et al. (2009) and Batty & Hudson-Smith (2012) argue that the combination of 3D representation and innovation in Geo-ICT has the potential to assists stakeholders, both authorities and local citizens, in managing their land and space. Cities must collaborate with society in land management. The digital transformation highlights the importance of a spatially enabled society to exploit land information. A combination of multidimensional representation and collaboration is believed to make a city and its society smarter. Recently, Michael Batty (2018) proposed 3D city models representing physical objects of a city and near real-time updating system (i.e., sensors) as a digital twin of a city. This chapter presents the development of 3D GIS that can perform two-way information flow among stakeholders for supporting Participatory Urban Plan Monitoring (PUPM). Also, this chapter introduces a digital triplets terminology to represent legal objects in the urban area. Similar to the digital twin, digital triplets use 3D representation and have updating systems to continuously mirror an abstraction of legal situations of objects in urban areas. Digital triplets shall accommodate a complete view of the legal situation and consist of information about Rights, Restrictions, and Responsibilities (RRRs) of an object (land parcel or space) in urban areas from four land management functions (land tenure, land valuation, land-use planning, and land development) (Enemark 2006 and Paasch et al. 2015). A participatory approach for urban monitoring has the potential to update and compare digital twin and digital triplets. This approach is taking the benefit of local citizens reporting a change in the urban area. Moreover, it can be applied to examine the conformance of the actual condition with prescribed legal documents from land-use planning. However, this information should be standardized as they correspond with the same reference, a three-dimensional space. This study considers the current policy and institutional rearrangement of the Spatial Information Infrastructure (SII) in Indonesia, transforming one-way data sharing and 2D to two-way collaborative and 3D capabilities. Furthermore, this study provides a prototype of participatory urban plan monitoring to develop two-way 3D information flows on the Open SII platform. The output indicates that our framework can support participatory urban plan monitoring in cities. This chapter is concluded with a focus on the effectiveness and efficiency of a two-way information flow for conducting urban plan monitoring involving local citizens. This study presents the development of a prototype of 3D Web GIS for PUPM. This prototype was designed to perform two-way information flows among stakeholders, allowing local citizens to access and contribute 3D spatial information for PUPM. This article presents the first attempt to conceptualize the digital triplets concept from 3D RRRs and develop a 3D user interface that enables two-way information flows and 3D web visualization for supporting participatory urban plan monitoring. Digital twins and digital triplets concepts depict the condition of an urban area in a more realistic representation. Local citizens can perform as a 'sensor' for digital twin and digital triplet. This study also considers the ISO 19152:2012 on Land Administration Domain Model (LADM) and national data governance policy to implement and deploy the prototype on the current National Spatial Information Infrastructure (SII) initiative. The proposed SP Package within LADM revision is used to construct a 3D representation of RRRs from land-use (urban) planning. This prototype is placed as part of the Indonesian national Geoportal for highlighting its capability to handle 3D visualization and two-way information flow.

2. PARTICIPATORY URBAN PLAN MONITORING IN INDONESIA

In 2016, the UN member countries adopted the "*New Urban Agenda*," a set of targets for cities to improve their planning practices and urban management for sustainable growth. UN-Habitat (2015) published "*International Guidelines on Urban and Territorial Planning*" to the UN member countries for organizing urban planning. this guideline recommends the local government "to set up multi-stakeholder monitoring, evaluation, and accountability mechanisms to transparently evaluate the plans' implementation and provide feedback and information on suitable corrective actions." According to this guideline, local governments establish a participatory mechanism that facilitates the effective and equitable involvement of stakeholders (including communities, non-government organizations, and businesses) to monitor and evaluate the implementation of urban plans. For this reason, *Bappenas* (2018) updated the Indonesian national urban policy. This policy attempts to handle uncontrolled land and space use and improve the quality of citizens' participation in sustainable development. The local government's inability and lack of citizens' involvement in monitoring, evaluating and controlling land and space use cause urban sprawls, land disputes, and illegal land use conversions in urban areas (*Bappenas* 2016).

Indonesia's Spatial Planning Act prescribes monitoring the implementation of the urban plan. Further, this Act mentions the "conformance" approach that observes and examines real-world implementations of the urban plans. The Spatial Planning Act allows citizens to monitor, evaluate, and report any Spatial Planning Act violations. The community's role in controlling land (and space) use is regulated in Government Regulations (68/2010) on the Form and Procedure for The Community's Roles in Spatial Planning. This regulation affirms openness as a core principle in monitoring the implementation of the urban plan, particularly by mandating all levels of governments to provide and share relevant data and respond to aspirations (including local knowledge) from local citizens. Specifically, the Spatial Planning Act instructs all governments' levels to develop and maintain an information system and its dissemination system to monitor, evaluate, and report the implementation of urban plans to society. The roles of the communities in land-use control are shown in Table 1. Moreover, this regulation specifies the information that should be provided in such spatial planning information system at the city level, which are: land policies, urban plans, and spatial planning programs that have already, being or will be implemented, as well as informational directives on guidelines, provisions on zoning regulations, permits, incentives, disincentives, and sanctions.

Table 1: Roles of the communities in land-use control (Spatial Planning Act & Govt Regulation 68/2010)

Roles
1. to provide a suggestion on zoning guidelines and regulation, permit, incentives, and disincentives; 2. to participate in monitoring and evaluating the implementation of an urban plan; 3. to submit a report to authorities in the event of any suspicion of irregularities or violation of land (or space) use following urban plans; and 4. to file an objection to authorities against any development that inconsistent with urban plans.

Government Regulation (15/2010) on Implementation of Spatial Planning prescribes a conformance approach in monitoring and evaluating the implementation of urban plans. In 2017, the Ministry of Cadastre and Spatial Planning released a Ministerial Regulation 15/2017 for providing guidelines in monitoring and evaluating spatial planning. This regulation only prescribes general documentation for monitoring and evaluation of the implementation of the urban plan. Although this regulation mentions the procedure for responding to reports from local citizens, it does not explain the role of local citizens in monitoring and evaluation. In the guidelines, monitoring activity is classified into two types: direct and indirect observations. Spatial information is used in both types of observations, while interviews are optional for direct observation. Government Regulation 15/2010 prescribes eight types of violations and eight types of infringements of land (and space) utilization. Indrajit et al. (2019) provide workflows for monitoring the implementation of an urban plan in Indonesia based on Government Regulation 15/2010. This workflow includes local government, communities, and non-government organizations as participants in urban plan monitoring. The procedure begins by examining conformity with zoning regulations. In the conformed case, the participant shall examine each zoning's actual function according to the expected function stated in zoning regulation. On the contrary, if participants find actual conditions inconsistent with zoning regulation, they can identify ecosystem threats (including safety, health, and environment). Participants may submit reports to the authority to check the permit's existence and validity over particular land (or space).

3. DIGITAL TRIPLETS FOR MONITORING IMPLEMENTATION OF AN URBAN PLAN

In 2014, the International Federation of Surveyors (FIG) launched "*Cadastre 2014 and Beyond*", the updated vision of Cadastre 2014, to advocate the acceleration of registration of the complete legal situations of land and space, including Rights, Restrictions, and Responsibilities (RRRs) (Kaufmann & Steudler 1998 and Steudler 2014). This updated vision also recommends a more robust data management through standardization, data quality assessment, and facilitating sharing of land information. Previously, Enemark (2006) proposes the land management paradigm that cities can implement to manage urban areas (and space) to put into good effect. This paradigm consists of four interacting functions (land tenure, land valuation, land-use planning, and land development) (Figure 1 and Table 2). This paradigm provides the scope of Cadastre 2014 (Steudler 2014) and recommends cities to standardize land information (Lemmen et al. 2019) and modernize their Land Administration System (LAS) (Enemark 2006).

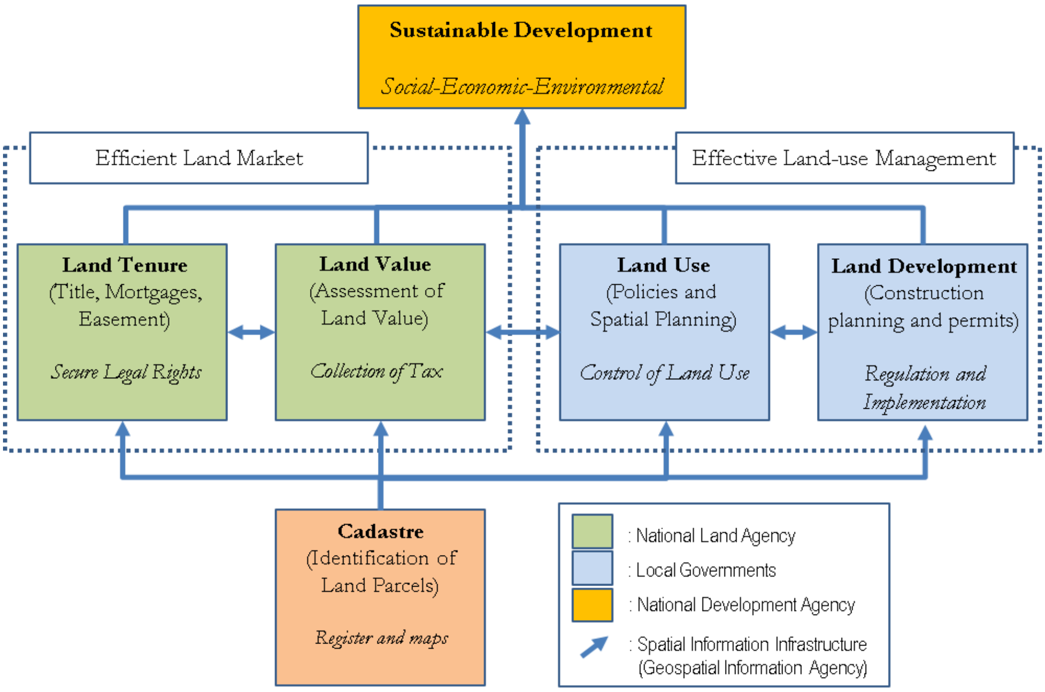

Figure 1. Actors and roles in land management and SII in Indonesia (Source: Enemark & Sevatdal 1999 and Indrajit et al. 2020a)

Table 2: Land management functions (Source: Enemark & Sevatdal 1999).

Cadastre	the legal surveys to determine parcel boundaries
Land Tenure	allocation and security of rights in lands, transfer (sale or lease) of property or use from one party to another, and management and adjudication of doubts and disputes on land rights and parcel boundaries.
Land Value	assessment of the value of land and properties (including land or property tax, management, and adjudication of land valuation, and taxation disputes.
Land-use	determination and control of land-use by adopting planning policies and land-use regulations, enforcement of land-use regulations, and management and adjudication of land-use conflicts.
Land Development	planning or building new physical infrastructure, implementing construction planning, and changing land-use through planning permission and granting permits.

A modern LAS should facilitate land-use control and land development towards effective land-use management. In 2012, ISO published ISO 19152:2012 of Land Administration Domain Model (LADM) for providing a guideline for countries and cities in establishing or improving their LAS. Many countries implement LADM to improve data handling and add '*machine-readability*' and '*machine-actionability*' of land information managed in their LAS (Van Oosterom & Lemmen 2015 and Steudler 2014). Starting in 2019, LADM is undergoing revision and improvement to modify existing core classes and add packages for land valuation and land-use planning (Lemmen et al. 2019). Accommodating more land management functions means adding more stakeholders to the land administration process. It requires interoperability of information in these functions and makes this information available and accessible for land management practices. Cities are recommended to integrate LAS with Spatial Information Infrastructure (SII) for land management as a step forward to make land information accessible to all stakeholders (including authorities, landowners, and economic actors). In the manufacturing domain, Umeda et al. (2019) propose a Digital Triplets concept as an extension of a digital twin to represent engineers and technicians' knowledge and skill. Digital Triplets aim to support engineers for crating values throughout the product life cycle from physical, digital, and intelligence activity in the industrial field. This article attempts to implement a city's digital triples by constructing physical, digital, and legal situations of urban objects (see Figure 2).

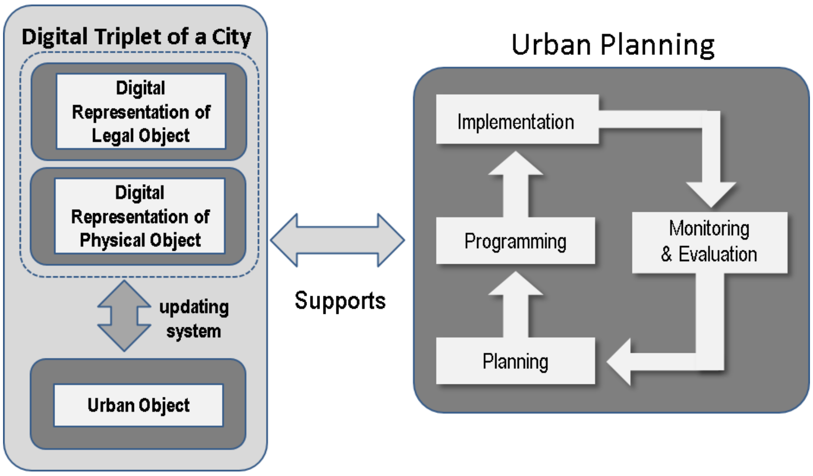

Figure 2. Digital Triplet of a City. Adapted from McLoughlin 1969 and Umeda et al. 2019.

3.1 Representing 3D RRRs from land-use plan

In 2006, the Committee on Support for Thinking Spatially in the US defined spatial thinking as "*a constructive amalgam of concepts of space, tools of representation, and reasoning processes*" (NRC 2006). The concept of space consists of knowledge, skills, and habits of mind. Spatial thinking enables description, explanation, and discussion of the Spatio-temporal process, including functions, structures, relationships, and operations in a city (NRC 2006). A suitable representation will improve stakeholders' insights and reasoning in presenting activity or phenomena (NRC 1997). The quality of decisions impacting humans and the environment can be achieved through information in higher resolution and dimensions (Kuhn 2005) that provides a more realistic view of a city's complex setting (Roche 2014). Urban planning departments have been widely using 3D city models for the past two decades (Ranzier & Gleixner 1997). These models contain various urban objects (i.e., buildings, trees, roads, pipelines, cables, water bodies). Murata (2004) demonstrates the potential of 3D spatial information for urban planning, such as: to visualize regulations in a complex urban setting, to compare the actual urban objects (e.g., building, public facilities) with regulation, to construct a simulation of the proposed urban development plans, and to facilitate consensus-building between stakeholders.

Frank et al. (2012) highlighted the usefulness of integrating RRRs from private and public laws and the need to have a 3D representation for a complete view of the legal situation of land parcels of urban space. The use of 3D city models is mainly for representing a snapshot of physical objects in urban areas. In comparison, Batty (2018) argues that a city needs to have a digital twin, a digital coupling of a city with a near real-time updating system. The digital twin concept is still emerging. This concept was developed in the manufacturing industry using a 3D model with actual dimensions and location (Grieves 2014). It consists of three parts: the physical object in real space, virtual representation in virtual space, and connecting tools between the physical object and virtual representation. Batty (2018) adopts this concept for cities and expects the birth of other digital couplings to model various abstraction in 3D representation. For example, planners and authorities develop criteria (privileges, prohibitions, and obligations) in the urban plan, translated into Rights, Restrictions, and Responsibilities (RRRs) to 3D space. However, the contemporary land-use plan exploits 2D visualization, while a complex urban setting is better represented in 3D to accommodate criteria constructed in urban planning (Indrajit et al. 2020). The 3D shape of a land-use (urban) plan depends on the regulatory system in a country. The height or depth dimension may be imposed for expected behavior to be performed by all actors in space, including an activity or rights (permission), restrictions (prohibitions), and responsibilities (obligations).

The International Organization for Standardization (ISO) published 19152:2012 on Land Administration Domain Model (LADM) standard to provide a model-driven architecture and a shared ontology needed by developing an effective cadastral system (Lemmen et al. 2015). The LADM working group is developing the Spatial Plan Information Package (SP Package) within the revision of ISO 19152:2012 (Lemmen et al. 2019). This package contains three core classes: *SP_PlanBlock*, *SP_PlanGroup*, and *SP_PlanUnit* (see Indrajit et al. 2020). *SP_PlanBlock* and *SP_PlanUnit* contain geometry and legal expression derived from the land-use (urban) planning process. LADM standard assigns RRRs information into three subclasses: *LA_Right*, *LA_Restriction*, and *LA_Responsibility* as administrative sources. The current LADM standard also provides *LA_BoundaryFace* class to construct a 3D representation of RRRs (ISO 2012). Representing Digital Triplets requires more than just geometrical models. They should manage semantic and topological aspects to represent urban objects for thematic queries and further analysis (Gröger et al. 2012). The Open Geospatial Consortium (OGC) published the *CityGML* standard to provide a foundation on geometry, semantics, visualization of objects, and semantics (Kolbe 2009 and Gröger & Plümer 2012). *CityGML* is an open-source database schema that stores objects and attributes in a hierarchical structure using Geography Markup

Language (GML). Many cities implement *CityGML* for managing their 3D city models (Biljecki et al. 2015). *CityGML* consists of twelve core modules: Appearance, Bridge, Building, *CityFurniture*, *CityObjectGroup*, *LandUse*, *Relief*, *Transportation*, *Tunnel*, *Vegetation*, *Waterbody*, and *Generics*. This format can only store all objects into a linear geometry structure. These core modules are supported in the 3DCityDB database system (Yao et al. 2018) with many real-life implementations. The 3DCityDB is an open-source database schema and a set of tools to import, manage, analyze, visualize, and export 3D spatial information (Kolbe et al. 2019). In 3DCityDB, a homogenous city object (i.e., building) shall be represented precisely as one object.

Although the *CityGML* standard's initial intention is to manage and exchange 3D city models, it can also publish 3D spatial information to the web. 3DCityDB currently provides several 3D visualization options for users to publish *CityGML* data, such as Google's KML (Keyhole Markup Language), *COLLADA*, and *glTF* formats. Publishing or exchanging the 3D city model directly in *CityGML* format is inefficient and requires suitable client-side plug-ins (Ohori et al. 2018). Many web technology options available for cities to publish their 3D spatial information as virtual 3D visualization over the Internet, such as *OpenLayers 3.0* (www.openlayers.org), *WebGL Earth* (www.webglearth.org), *OpenWebGlobe* (www.github.com/OpenWebGlobe), and Cesium (www.cesium.com). Cesium technology is an open-sourced software that enables users to explore 3D spatial information on a web browser without any installation. Many cities combine *CesiumJS* with *3DCityDB* (Yao et al. 2018) for its high-performance, 'mashups' and cross-platform visualization capabilities (Prandi et al. 2015). *CityGML* has a *LandUse* object model representing the 2D surface assigned for planned land use (see Gröger et al. 2012). Digital triplets can be in the form of buildable area (or space), 3D (space) parcel, or 3D mining rights. The granularity of digital twin and digital triplets follows the Level of Detail (LOD) proposed by the Open Geospatial Consortium (OGC). Biljecki (2017) defines LOD as "*an indication of how thoroughly a 3D city model has been modeled and as the degree of its adherence to its corresponding subset of reality*". LOD is classified into five grades based on visualization, accuracies, and minimal dimensions of objects (OGC 2006). OGC includes LOD types within *CityGML* standards to represent the city's objects in three multidimensional formats.

3.2 Updating mechanism: citizens as urban sensors in urban plan monitoring

Today's cities are using spatial information for various applications and analyses. Moreover, Geo-ICT is proven to improve society's ability to plan and manage urban areas and making a city smarter (Batty et al. 2012, Daniel & Doran 2013 and Roche 2014). 3D representation and Geo-ICT and its combination are considered as enablement to open ample opportunities for cities to manage their land (and space) (LeGates et al. 2009 and Batty 2018). If this combination is shared with relevant stakeholders, it will improve the spatial thinking and cognitive ability needed to plan and manage a city (Roche 2014 & 2017). Since the last decade, citizens' ability to use spatial representation to monitor their livelihoods improves (Arsanjani et al. 2015, Crooks et al. 2015, and Herfort et al. 2019). In 2007, Michael Goodchild introduced "citizens as sensors" terminology for an alternative source of mapping. Participatory mapping gains popularity among local citizens in many countries, facilitating their local knowledge to a map (Goodchild 2007). They are provided with reference maps (or imagery) and tools to contribute spatial information to the participatory urban monitoring system.

Minang & McCall (2006) define Local Spatial Knowledge (LSK) as local knowledge generated by local citizens that offering a unique description of land or space. In 2008, Sarah Elwood stressed that citizens require land information to contribute local knowledge (Elwood 2008). In the participatory approach, sharing (land) information to all participants would be the foundation of a participatory approach and influential to the quality of participation contributed to the initiative (Arnstein 1969 and Wilcox 1994). Later, Goodchild (2009) introduced the term "*Neogeography*" for alternate map-producing techniques from crowdsources, contributors other than experts and professionals. He classified Volunteered Geographic Information (VGI) as maps produced from *Neogeographers* using advanced Geo-ICT innovations, such as mobile mappers and unmanned aerial mapping systems. There are success stories of cities organizing a facilitated VGI, using web mapping interfaces to allow local citizens, individually or in groups, to contribute local knowledge in the form of a map with a predefined set of criteria to a specific geographical extent (see Seeger 2008). Local citizens are the custodian of Local Spatial Knowledge (LSK) as they hold local knowledge of physical objects or phenomena that scientist and professionals do not (McCall & Dunn 2011). However, they need certain spatial information used as reference and tools to contribute their LSK on maps for maintaining preciseness, including in Participatory Urban Plan Monitoring (PUPM). Therefore, the existing SII should be improved to enable two-way information flow among stakeholders and manage and disseminate multidimensional spatial information. This chapter presents the development of a user interface built on an open spatial data sharing for PUPM using the proposed SP Package of LADM revision.

In participatory urban plan monitoring, the quality of information flows should be carefully designed and managed. This chapter follows the quality of the information flows concept proposed by Gudowsky & Berthold (2013) for developing open participation in the SII. The concept of quality of information flows is classified into four classes: one-way and two-ways, depending on the recipient's understanding, media, and timing of the data. The one-way flow consists of *uni-directional* and *bi-directional* dimensions. The *one-way* information flow among stakeholders can be found in most SII, where topographic maps are published as open data to a broader community. *Uni-directional* is the most commonly used in sharing the map with no right for citizens to negotiate. Simultaneously, the *bi-directional* flow is two reciprocal *uni-directional* flows without obligation to consider information from the other side. In contrast, a *two-way* information flow has two types: *discussion* and *dialog* (Gudowsky & Berthold 2013). *Discussion* allows spatial information sharing to meet a consensus through arguments or constructive disagreement. *Dialog* enables stakeholders to experience the free flow of information to improve understanding of the specific topic. Open participation requires two-way flows where information exchange has more intensity between stakeholders in *discussion* or *dialog*.

4. CONSTRUCTING 3D URBAN PLAN FOR INDONESIAN CITIES

In the Indonesian regulatory system, urban areas are divided into zones of spatial designation depicted in the urban plan map. Local governments use zoning regulations to ensure quality land or space functions, minimize unintended land or space utilization, and preserve the environment. In each zone, specific restrictions and responsibilities are imposed to regulate location, activities, land-use intensity, and building code. Land-use (urban) plans are used as a reference for controlling land or space utilization, granting land or space utilization permits (including air and underground utilization rights developments), determining incentives, imposing sanctions, and providing technical guidance in urban development. The spatial Planning Act commands Indonesian cities to develop zoning regulations for determining basic rules and techniques for zoning arrangements.

Basic rules constitute requirements for spatial use, including conditions for activities, land use criteria, land-use intensity, building codes, provision of necessary infrastructure and public facilities, special regulations, technical standards, and implementation guidelines. The Techniques for Zoning Regulation (TZR) were implemented in Indonesian cities to allow flexibility in applying zoning rules. TZR is also helpful in overcoming various problems in implementing necessary zoning regulations, taking into account the contextual conditions of the area and the direction of spatial planning (Ministry of Cadastre and Spatial Planning Regulation 2018). TZR consists of Transfer Development Right (TDR), Zoning Bonus, Conditional Uses, Performance Zone, Fiscal Zone, Development Agreement, Overlay, Threshold Zone, Flood Zone, Special TZR, Growth Control, and Preservation of Cultural Heritage. The Ministerial or technical regulations are also considering multiple aspects for height limitation. For example, the Minister of Cadastre and Spatial Planning Regulation (2018) provides a guideline on setting the limit of the height of high-density vertical housing areas to 40 meters. While for landed high-density housing areas, it is only 10 meters allowed by this regulation. It is measured from the ground to the maximum distance of the roof. For other zoning types, authorities apply the height limitation (H_BuildingEnvelope) for each lot depending on its zoning type. It considers Air Safety Operation (ASO), Fire hazards (F), Property's optimal prices (P), Floor Area Ratio (FAR), Land Use Intensity (LUI), Sky Exposure Plane (SEP), Angle of Light (AOL), Wind speed (WS), Earthquake (EQ), and Transportation (T). Thus, the third dimension of a building envelope can be determined as follow:

$$H_{BuildingEnvelope} = f(ASO, F, P, FAR, LUI, SEP, AOL, WS, EQ, T)$$

On the type of land function, each allotment contains a set of zoning requirements. These requirements may be represented with a 3D RRRs object with dimensional requirements (i.e., maximum building heights, ground-floor area coefficient, total-floor area coefficient, free distance limit, and borderline distances).

5. A WEB-APPLICATION FOR PARTICIPATORY URBAN PLAN MONITORING

In 2020, the Indonesian parliament passed the *Cipta Kerja* (Job Creation) Act, often called the Omnibus Law. 3D cadastre is included and highlighted in this Act by assigning rights for *Hak Guna Bangunan* (rights to utilize construction), *Hak Pakai* (rights to use), or *Hak Pengelolaan* (rights to manage) in space above, on, or below the surface. The Job Creation Act transforms RRRs from 2D to 3D representation by specifying land use for below, on, or above the surface and governing rights of access for utilities (i.e., cables) over or below land or space. The volumetric (height and depth) limitation of land rights (rights of space) is introduced explicitly by including maximum building heights, ground-floor area coefficient, total-floor area coefficient, free distance limit, and borderline distances into 3D RRRs. Moreover, this Act puts more burden on an urban plan as it accommodates environment impact assessment and building code into *Rencana Detil Tata Ruang* (RDTR) (detailed urban plan).

Consequently, Indonesian cities need to develop 3D RRRs consisting of the four functions of land management (land tenure and cadastre, land value, land-use, and land development, see Enemark 2006). In 2018, GOI launched the Online Single Submission (OSS), an online platform connecting various sectors to issue permits and business licensing and investment at all government levels (Ministry of Trade 2018). The OSS functions as a single national gateway for issuing permits and business licensing. Therefore, 3D RRRs should be the core data in a permit system, such as the OSS. The spatial plan information package from the revision of ISO 19152:2012 has the potential to provide a foundation for standardizing urban plan information and zoning regulations to be used for the OSS. New guidelines for implementing technical aspects of the Spatial Planning Act are provided by the Ministry of Cadastre and Spatial Planning Ministerial Regulation 14/2020 on Guidelines on Development of Spatial Planning Database (DSPD). The ministerial regulation contains guidelines on DSPD to ensure information interoperability and consistency of the land-use plan. It provides standardization of the spatial plan feature class, including format, storage structure, the naming convention for a spatial plan, and detailed spatial plan (urban plan). This guideline mentions geometric aspects in limited aspects, covering 1D (point) and 2D (line and polygon) primitives. It still has not provided 3D primitives that regulations and smart cities demand.

5.1 Workflow for Participatory Urban Plan Monitoring (PUPM) application

Based on Government Regulation (68/2010) on the Form and Procedure for the Community's Roles in Spatial Planning, this study develops a workflow that allows citizens to participate in urban plan monitoring. The workflow determined for roles for performing tasks stated in Table 3: End-Users, Contributors, Contributors-Geometry, and Validators. This workflow enables all types of stakeholders identified in Table 5to perform roles assigned for participatory urban plan monitoring. This study uses the existing urban plans of Jakarta and Bandung City that implement height (and depth) thresholds to construct a volumetric form of 3D RRRs. This study also includes 3D city models of these cities to improve the spatial thinking of all stakeholders. With 3D RRRs and 3D city models, the PUPM application constructs digital twin and digital triplets of Jakarta and Bandung and enables all stakeholders to virtually monitor urban plans. The PUPM application can be accessed through https://tanahair.indonesia.go.id/pupm. This study constructs PUPM workflow to enable two-way information flow, facilitating data collection and consensus-building between contributors and validators to collect and verify LSK on the implementation of the urban plan. This activity can be attained through (1) accessing 3D city models (digital twin) and 3D RRRs (digital triplets), (2) comparing actual conditions with 3D RRRs by updating land (or space) functions, and (3) modifying the existing 3D city models with updated (and more realistic) records with multimedia files (Figure 3).

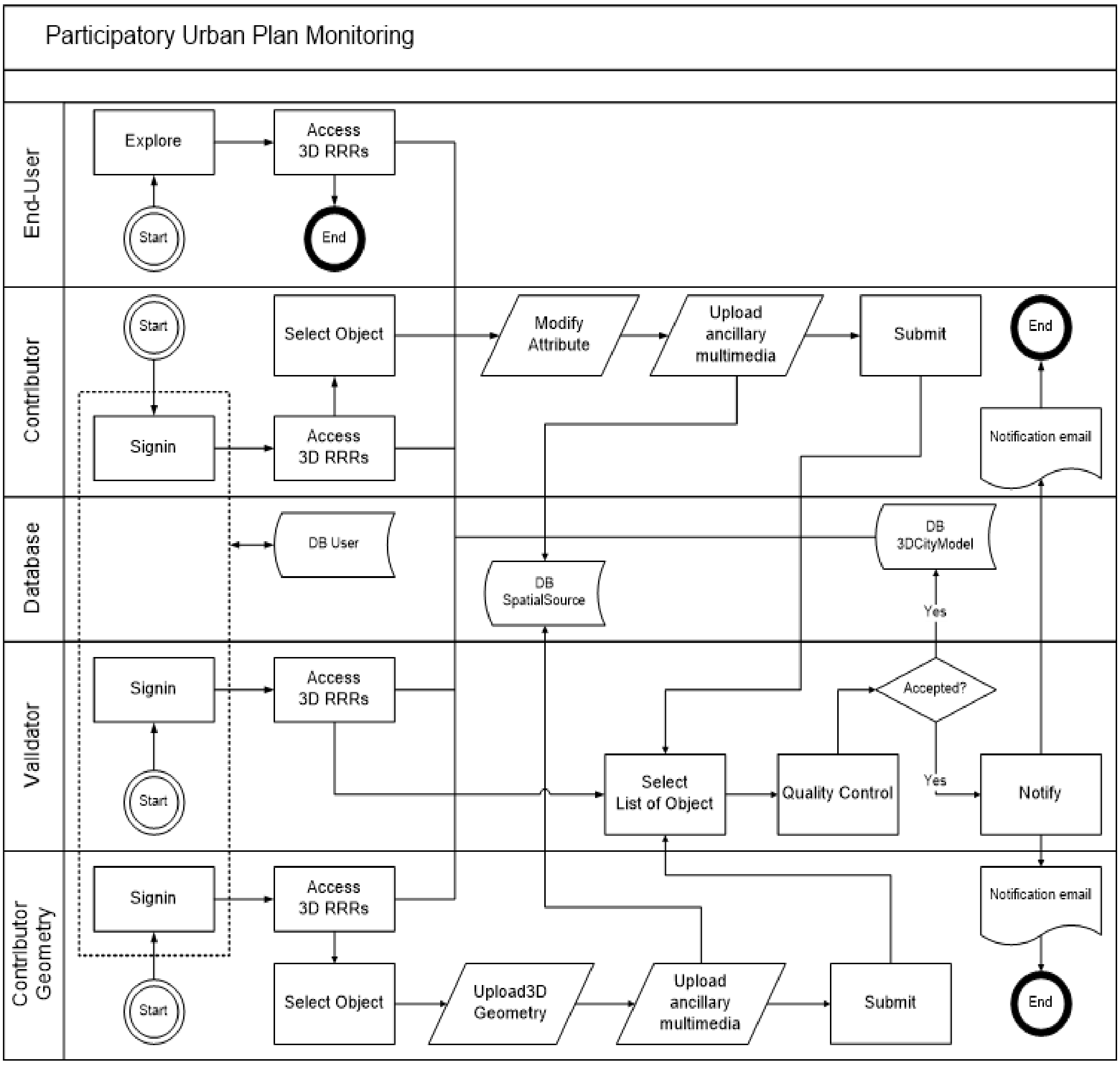

Figure 3. The workflow of the PUPM application

The PUPM application involves four roles in urban plan monitoring: contributor geometry, validator, database, contributor (attribute), and end-users (see Table 3). The four roles determined in this study are to accommodate the roles prescribed on Government regulation

(68/2010). Contributors and geometric contributors can modify attributes and upload a 3D file with a multimedia file as a supporting confirmation. Both contributors then submit these files to the PUPM system. A web-based application was developed to support monitoring the implementation of an urban plan that allows participants to access 3D urban plans and contribute 3D building with land (or space) actual utilization. The workflow is using the "conformance" approach that compares actual conditions with urban plans. Local citizens may follow the workflow to monitor and report the urban plan infringements.

Table 3: Roles and privileges in participatory urban plan monitoring

Roles	Access	Generate/update		Validate
		attribute	maps	
end-users	☑			
contributor (attribute)	☑	☑		
contributor geometry	☑	☑	☑	
validator	☑	☑	☑	☑

5.2 The spatial database for 3D RRRs from urban plans

Urban plan in Indonesia is governed by public law that consists of Rights, Restrictions, and Responsibilities (RRRs) prescribed in a zoning regulation for each zone. Currently, Jakarta and Bandung are still managing urban planning with 2D representation and not complying with the newly enacted guideline from the Ministry of Spatial Planning Regulation (2020). On the other hand, the Job Creation Act requires 4D topology, a 3D geometric representation with temporal managed as an attribute of urban plans to support the permit system. The OSS system also prescribes standardization to ensure *machine-readability* and *machine-actionability* for all data, including urban plans. However, Jakarta and Bandung have not standardized their urban plan according to current national or international standards. Therefore, this study includes construction 3D representation and information interoperability to comply with the newly enacted guideline from the Ministry of Spatial Planning Regulation (2020) for Jakarta and Bandung's urban plans and the proposed SP Package LADM. This study includes versioning capability to urban plan database to enable comparison or monitoring and evaluation tasks in participatory urban plan monitoring. The height dimension is sourced from the zoning regulation or '*building envelope*' of each zone. The height value is computed and enforced by local governments using algorithm 1 in Section 4. This study implements the SP Package as part of the revision of ISO 19152 on LADM for ensuring interoperability between land management information, specifically *SP_PlanUnit* and *SP_PlanBlock* classes and its code lists. The core LADM data models and code lists are applied to manage common land management information. *LA_BoundaryFace* class of LADM was used to construct a 3D representation of urban plans for Jakarta and Bandung City. Implementing the *SP Package* on Jakarta and Bandung urban plans could be done smoothly. These maps contain height limitation parameters and have sufficient quality in geometric, logical consistency, and semantics. These urban plans are developed upon large-scale topographic maps (1:1000 and 1:5000) but apply their semantics standards.

The 3D spatial representation of urban plans is transformed into *CityGML* standards using *Feature Manipulation Engine* (FME)® of *Safe Software* before being loaded into the *3DCityDB* database. Two actual urban plan of Jakarta and Bandung city is stored in *3DCityDB* in *CityGML* format for supporting the PUPM application. These urban plans are then converted to a 3D tileset using a batched 3D model (b3dm) format for faster interaction at the client-side. The PUPM application prototype provides a minimal topography map published from global map services for adding locational context and spatial references for its users. The 3D database was designed to allow contributors to upload their building data. This study applies a non-linear geometry to comply with all possible shapes commonly formed to polygons in urban plans. For representing an urban lot in 3D, this study selects *gml:MultiSurface* due to irregular surfaces. *CityGML* standard provides a minimalist option for an urban plan in three types of attributes: class, function, and usage. LOD1 was used to represent 3D urban plans in Jakarta and Bandung cities with semantic standards follow the *SP Package* of LADM revision. The PUPM application is supported by a 3D spatial database using *PostgreSQL* and structured following the 3DCityDB version 4.20 (Figure 4). Temporal information is managed as *VersionedObject* to document change over time. The standardized spatial database aims to maintain and preserve data integrity, appoint authorized data custodians, provide 3D RRRs and building data to users using a common data model (LADM) in a simplified way, and ensure interoperability for urban plans in a federated system. However, this study only provides a basic form but representative for exposing LADM and 3RRRs derived from the urban planning process for participatory urban plan monitoring. *CityGML* was used for its capability to support wide ranges of 3D geometry with temporal information managed as an attribute.

5.3 The spatial database for 3D RRRs from urban plans

The PUPM application (beta version) facilitates local citizens' participation in the urban planning process by providing participatory urban plan monitoring tools. This application is developed through web 2.0 technology to optimize outreach to local citizens with minimal barriers. This study develops a 3D spatial database capable of managing the OGC's *CityGML* standards. The *3DCityDB* was installed in *PostgreSQL* to store and manage *CityGML* data for digital twins (buildings) and digital triplets (urban plans). An overview of the server-client architecture is presented in Figure 4. The server-side consists of a 3D spatial database, *Geospatial Content Server* (GCS), and web-based user interface. The *3DCityDB* was used for managing 3D building data and 3D urban plan, while CesiumJS server-side publish these data in 3D visualization. The PUPM application is installed as part of the Indonesian Geoportal and can be accessed openly through hhttp://tanahair.Indonesia.go.id/pupm.

5.3.1 Accessing 3D urban plan

This application offers standard capability provided by *CesiumJS* ™, an open-source platform for delivering 3D spatial information. CesiumJS is an open and free software to disseminate 3D spatial information without installing anything on the users' side. As Cemellini et al. (2018) highlighted, *CesiumJS* can provide navigation, hovering tooltip, mashing-up with multiple layers, transparent coloring and highlighting, searching and querying 3D objects, and advance viewing. The PUPM application uses caching and 3D tiling techniques to communicate between the server and the client sides when opening and exploring the area. It visualizes RRRs in 3D from a spatial database following LADM standards on the server-side (see Figure 5 & Figure 6). At the client-side, a user interface based on WebGL was developed for users for visualizing, querying, interacting and submitting 3D spatial information in participatory urban plan monitoring. Based on surveys and interviews conducted in 2017 and 2019, stakeholders preferred a volumetric shape of the urban plan to represent the building envelope and 3D RRRs. However, it will need a high-quality Digital Terrain Model (DTM) comparable to at least LOD1 or at a map scale of 1:1000. This terrain data will be used as a height reference for 3D spatial information (building and 3D RRRs). As online terrain data is only available at a medium or smaller scale (less than 1:25.000), this study regards all spatial information in zero elevation (flat earth surface) to avoid misrepresenting the building's height and building envelope.

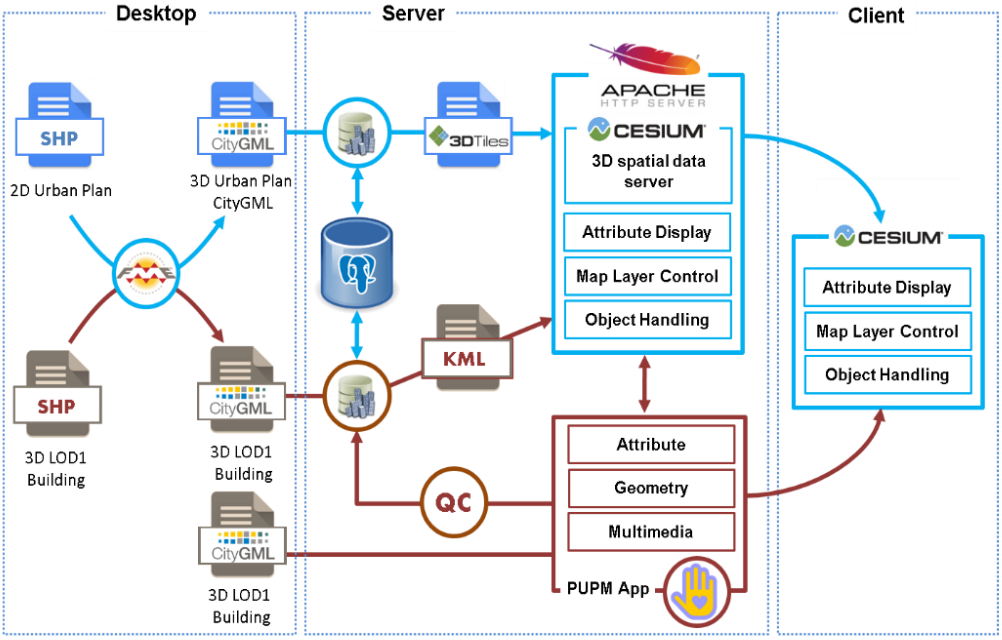

Figure 4. Configuration of 3D Database and 3D Visualization of PUPM

5.3.2 Contributing and updating 3D building information

The PUPM application facilitates users to interact with 3D urban plans of Jakarta and Bandung City. A custom-made python script is used to enable automatic loading of CityGML files containing 3D building into *3DCityDB*. This study also enables automatic quality control provided by *3DCityDB* to validate attributes and geometries before updating the database. The PUPM prototype is also converting the newly submitted to KML format. 3D tileset (KML) contains building information and urban plan contributed by all stakeholders. The PUPM preserves information from users and is validated by the authority as a versioned object for temporal information. The temporal data will allow 3D land-use change analysis, which is planned to be developed in the next version of PUPM. For the initial implementation, this study provides 3D building in LOD-1 and LOD-2 for one district in Jakarta and two districts in

Bandung City in *gml:Multisolid* format. This format allows users to query a building in city-wide data. Users are also provided five sets of buildings in CityGML format to contribute 3D spatial information into the PUPM system.

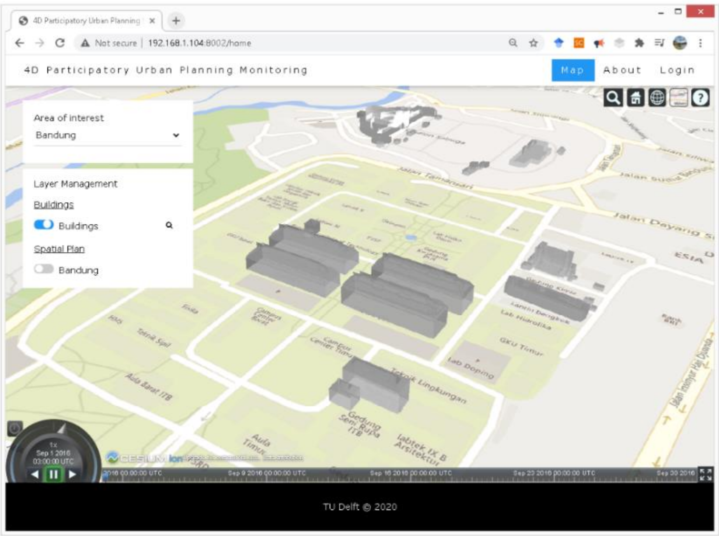

Figure 5. Overview of Digital twin (3D city model) for the end-user interface (Location is Institute Technology of Bandung Campus at Bandung City, Indonesia)

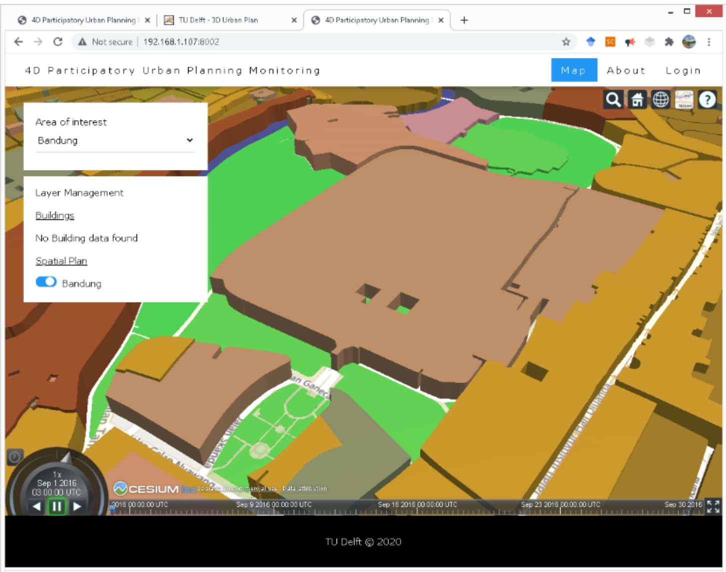

Figure 6. Overview of Digital triplets (3D city model) for the end-user interface (Location is Institute Technology of Bandung Campus at Bandung City, Indonesia).

5.3.3 Validating contributed 3D building data

In an exemplary implementation, PUPM shall use ISO 19157:2013 on Data Quality to examine both geometries and attribute data submitted into the system. However, the PUPM version 1.0

only examines the Logical Consistency of data submitted by contributors. This functionality is part of the *3DCityDB* importing and exporting tool operating in batch mode triggered by the validator role. This tool is configured to detect and validate XML data containing 3D buildings in LOD 1, LOD2, and LOD3. Validators may use their desktop-based software for assessing other data quality elements prescribed in ISO 19157:2013 (i.e., Completeness, Positional Accuracy, Temporal Quality, and Usability Elements). There is free and open-source software available for examining data quality elements available for validators and users to convert or asses data in CityGML format (http://www.citygmlwiki.org/index.php/Freeware).

6. USABILITY ANALYSIS

The purpose of usability analysis is to help developers to improve the PUPM application. ISO 9241-11:2018 defines usability as "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.*" Usability testing is intended to gauge how the PUPM application will be used by a broad range of users with different knowledge and skills in utilizing Geo-ICT. The usability test attempts to resemble reality but not the actual situation and will not declare the PUPM application reliable. ISO 9241-11 prescribes usability testing to measure three attributes: effectiveness, efficiency, and user satisfaction. However, this study only applies informal usability testing, as highlighted by Nielsen (1994), to gauge effectiveness, efficiency, and user satisfaction.

6.1 Preparation

The usability test was performed in October 2020 in an online form with explanation and assistance through a virtual meeting. The questionnaire was designed specifically for individuals that have Local Spatial Knowledge (LSK) of a selected site. This study selected the Institute Technology campus for usability testing, and the participating students were considered '*local citizens*.' The questionnaire asked respondents to simulate how local citizens contribute LSK to the PUPM application. Forty-nine respondents participated in a usability test; see Figure 7. The respondents performed all tasks of four roles prescribed in the questionnaire. This study assigns respondents to the type of stakeholders; see Table 4.

Table 4: Respondents and type of stakeholders

Respondents	Potential type of stakeholders
Visitor	NEO
Undergraduate & Graduate Students	
▪ Geodesy or Geomatics	EAUTH, EPRO, EAMT, IAMT
▪ Architecture	EAMT, IAMT
▪ Urban Planning	EAUTH, EPRO, EAMT, IAMT
▪ Civil Engineering	EAMT, IAMT

6.2 Assessing effectiveness and efficiency

This study implements a post-release assessment using on-site testing to evaluate the effectiveness of the PUPM application in the user's environment for improvement. In this approach, developers invite users to perform several tasks, evaluate and validate the usability (Barnum 2011, pp 81-82). The usability test started with a brief description of the PUPM application. The respondents had to explore all functionality by themselves and relate to the sections in the questionnaire. This study gave respondents six tasks via an online meeting application to assess the effectiveness and efficiency of the PUPM application1. The first task is to make the user familiar with functionalities. Task 2 aims to provide experience with multidimensional representation. The third task requested respondents to use provided tools to update buildings' characteristics, including the type of land-use, building height, and recent pictures. These tasks were explicitly designed for respondents familiar with the test site (ITB campus) and to let them experience four roles in the PUPM application via online form. The questionnaire contains a straightforward explanation for each task and can be used as a guideline for completing tasks. In the usability test, 49 respondents representing three groups are expected to assess the effectiveness of the PUPM application. The questionnaire was performed during lockdown time, so most respondents used home internet facilities or mobile tethering devices. Almost all respondents are young people under 30 (48 out of 49), and 63.3% female. Seeing 3D urban plans will be the first time for all respondents, and more than 75% of respondents were self-declared to have sufficient knowledge and GIS skills (score seven and above). However, almost half of the respondents assessed themselves as having less knowledge and skill in 3D spatial data and 3D visualization.

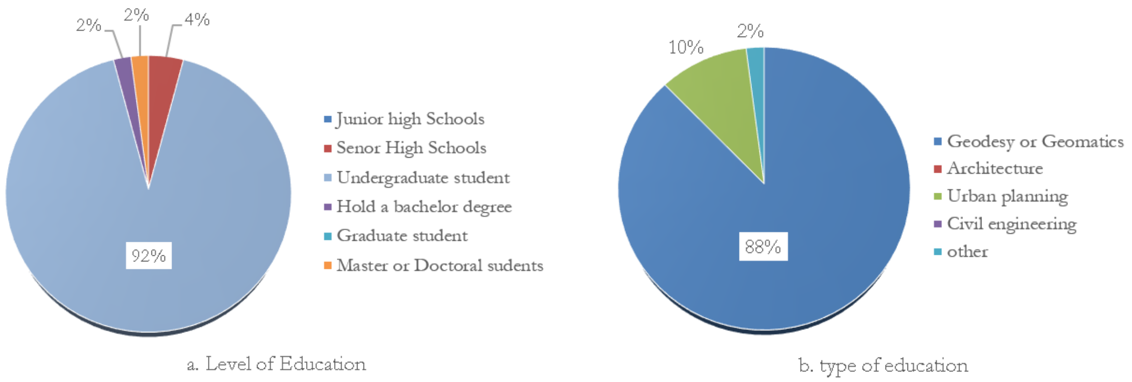

Figure 7. Characteristics of Respondents

There is only 57.8% of respondents were aware of the importance of the 3D urban plan. All respondents are familiar with the location (ITB campus), with 92% working or studying at the location (42 respondents from the geodesy and geomatics department). From the questionnaire, the PUPM application was proven to enable users to perform given tasks (see Table 5) for accessing and contributing 3D spatial information for monitoring the implementation of urban

[1] The online form can be accessed through: https://forms.gle/edsjq2RcmGQ22V758

plans. Most of the respondents (75.5%) succeeded in using navigation tools to locate a point and prove relative position through the screen with the standard tool provided by Cesium viewer. However, some respondents (33%) cast low scores (six or below) on smoothness or unresponsive screens on their laptops at home.

Table 5: Six tasks for assessing the PUPM application

Task 1:	to get familiar with the functionality, including the type of users, buttons (pan, zoom, and other control), and process
Task 2:	to understand 3D urban plans and 3D building information
Task 3	to contribute or update attribute of a building (including photo and video) in two-way flows
Task 4:	to contribute new 3D building data in two-way flows
Task 5:	to see the history of changes in a building
Task 6:	to validate submitted data

6.3 User's satisfaction

The respondents reported some delays due to slow internet connection performance with big-sized data transfer, particularly on loading 3D urban plans for the whole city. The PUPM requires a high-speed Internet connection, which the home internet infrastructure in Indonesian city still lacking. Indonesian internet speed. However, they cast high grades (85%) on tools for navigating on-screen. More than half (56%) of respondents still had difficulty identifying height violations of the urban plan visually. The respondents score only average grade for updating attributes (average grade 5 of 10) and contributing 3D building data (average grade 5), which did not satisfy many portions of respondents' demand. The PUPM application was valued slightly better (average grade) to provide urban plans access in 3D representation and buildings' historical data. The problem encountered by the PUPM application was mostly about slow responses accessed from respondents' home internet devices. It would be expected to improve 3D data delivery through slower internet access to gain more users' satisfaction.

6.4 Summary

From the usability test, this study found three interesting facts to be considered in developing an application for PUPM: (i) stakeholders were adaptive to two-way information flows for co-producing urban information; (ii) the use of multidimensional representation for the physical and legal object were beneficial for PUPM; (iii) exchanging multidimensional spatial representation using internet technology is relying on communication infrastructure.

7. CONCLUSIONS AND FUTURE RESEARCH

7.1 Conclusion

This article aims to study the implementation of a two-way information flow using multidimensional representation for PUPM. This study is the first attempt to conceptualize the digital triplets concept from 3D RRRs and develop a 3D user interface that enables two-way information flows and 3D web visualization for supporting participatory urban plan monitoring. The exploitation of 3D representation for land management is considered beneficial to improve spatial thinking and monitor and evaluate the implementation of the urban plan. Compared to the 2D visualization, Representing Rights, Restrictions, and Responsibilities (RRRs) using digital format over the two biggest Indonesian cities' internet seem to leverage the discussion toward monitoring and evaluation targets easier. The PUPM application can minimize unnecessary debates (or even conflict) caused by interpretation of physical characteristics of a violation of urban plan and creating more time to explore solution creation. The spatially enabled government and society were determined in continuous improvements for Indonesia's smart city project. Indonesian government declared a clear and well-defined action plan for developing a 3D urban plan to accompany the 3D cadastre as mandated in the recently enacted Job Creation Act (2020). Jakarta and Bandung City's government needs to develop digital triplets for representing the legal object to accompany digital twin (for physical objects) in their smart city system. The study found four aspects to be highlighted for PUPM: (i) standardization will ensure information interoperability in land tenure, land valuation, land-use planning, and land development planning; (ii) the web application may be suitable for maximizing outreach. The performance of the PUPM application is highly dependent on the quality of ICT; (iii) 3D spatial representation enables users to identify dimensional compliance of building with urban plans; and (iv) a two-way direction was successfully facilitated by the PUPM application to monitor the implementation of the urban plan. However, this application has gaps to address, mainly optimizing 3D data delivery to the potential contributors with minimal internet access.

7.2 Future Research

As mandated by the spatial planning regulations, local governments in Indonesia must develop a GIS for Spatial Planning (GISTARU) to support the spatial planning process. Making 3D urban plans accessible may add more attention to participants to contribute to the GISTARU to present the actual condition with more realistic visualizations. This study may stimulate more research for:

a) Improvement of Geo-ICT facility for supporting 3D data delivery. Disseminating and contributing 2D spatial information requires a sophisticated ICT infrastructure and systems, let alone 3D data. In the digital transformation era, where most of the data transfer is through the Internet, a smart city should consider 3D data delivery of its ICT infrastructure. There is an urgent need to study the integration of Open SII with the smart city ecosystem capable of delivering digital twin (to represent physical objects) and digital triplets (representing legal objects) to society helps add spatial enablement of a city.
b) Upgrading 3D building information contribution and updating module. BIM stands for Building Information Modelling and is a 3D model-based process used across the building design and construction process to efficiently design buildings and plan every stage of building. The use of BIM technology in construction project management is increasing in the last decades. 3D models from BIM can be utilized for data input of the PUPM application.

c) Standardization of four functions of land management. Interoperability is vital for information integration, including for participatory monitoring of the implementation of the urban plan. In Indonesia's two biggest cities (Jakarta and Bandung), 3D representation of RRRs is also essential for land development planning, particularly for urban planning and monitoring and granting businesses and investment permits. Therefore, further research is expected to find a better solution to improve digital triplets that contain a complete view of the legal situation for land parcels and urban space.
d) Development of 3D visualization capability for a smart city. A smart city must consider the representation of its legal objects, not only for improving the city's income (i.e., taxation) and social protection (i.e., disaster management) and monitoring and evaluating its urban plan performance and enforcement. Therefore, more research on 3D RRRs for smart cities that cover objects below, on, and above the surface is required. This study opens opportunities for a comprehensive framework for developing, maintaining, and sharing digital twin and digital triplets for smart cities.

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