Modelling and Verifying Land-use Regulations Comprising 3D Components to Detect Spatio-Semantic Conflicts

Thèse

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Résumé

L’utilisation du territoire est régie par différents mécanismes que nous pourrions nommer géorèglementations comme par exemples les plans d’urbanisme, les permis de construire ou le zonage. La géorèglementation, en anglais, on parle de Land-use Regulation (LuR), permet d’imposer ou d’influencer l’utilisation d’un territoire dans le but d’atteindre des objectifs de politique publique. Qu’on le veule ou pas, la géorèglementation est nécessaire car elle permet de consolider une saine gestion des ressources, elle aide à la conservation et au développement du territoire, elle fournit un cadre législatif important pour assurer la sécurité et le bon fonctionnement pour l’accès et l’utilisation harmonieuse du territoire.

La géorèglementation s’applique donc sur un territoire, où les composantes spatiales, comme la géométrie des éléments, sont primordiales. Il faudra par exemple tenir compte des marges de recul (donc distance) lors de la construction d’une maison, d’une superficie maximale de construction, etc. Ces composantes spatiales du territoire et son occupation peuvent également faire intervenir la 3e dimension comme la profondeur, la hauteur ou encore le volume. La pratique et la littérature montrent que la géorèglementation est actuellement principalement décrite dans des documents de planification et des lignes directrices, dont certains peuvent inclure une représentation spatiale en 2D (i.e. des cartes). On retrouve parfois de coupes transversales en 2D pour représenter l'étendue 2D/3D des LuRs. Cette manière de travailler à partir de document manuscrit et de plans 2D présente des lacunes importantes. Elle limite la possibilité d’avoir une compréhension complète et adéquate de l'étendue 3D des LuRs et donc dans la prise de décision, comme par exemple, la détection de conflits potentiels dans la délivrance de permis de construire ou d'aménagement. De plus, l’application et donc la validation de ces géorèglementations à partir de documents descriptifs prend du temps et laisse place à la subjectivité, ce qui peut conduire à de mauvaises décisions. Les autorités en matière de planification territoriale devraient avoir accès à toutes les informations et à toutes les représentations spatiales requises pour évaluer les LuRs et détecter les conflits potentiels. Force est de constater, que ce n’est pas le cas actuellement, et que même si des modèles 3D de bâtiments (BIM) ou de ville (CityGML) ont vu le jour, ils ne sont pas intégrés dans ces processus de géorèglementation.

Cette recherche doctorale est dédiée à la conception et au développement d'un cadre de référence pour la modélisation géométrique 3D des LuRs, leur intégration dans le contexte des modèles de ville 3D et la détection automatique des conflits spatio-sémantiques potentiels lors de la validation des LuRs. Ce cadre de référence vise donc à soutenir les autorités en matière d’application de géorèglementations. La recherche se décline en cinq sous-objectifs soit **1)** proposer un inventaire des différents LuRs 3D en précisant leurs composantes 3D/verticales, **2)** proposer une classification fonctionnelle basée sur l'ampleur des conflits potentiels des LuRs 3D pour soutenir la prise de décision des autorités, **3)** modéliser les LuRs en 3D puis les combiner avec d'autres sources d'information (ex. BIM, CityGML et cartes de zonage), **4)** détecter les conflits spatiaux et sémantiques potentiels qui pourraient survenir entre les LuRs modélisés et les objets physiques comme les éléments de construction et, **5)** concevoir et développer une preuve de faisabilité.

Parmi plus de 100 de géorèglementations 2D/3D passés en revue, 18 de géorèglementations 3D sont inventoriées et discutées en profondeur. Par la suite, pour chacune de ces géorèglementations, les informations et paramètres requis pour leur modélisation 3D automatique sont établis. L'approche proposée permet l'intégration de la modélisation 3D de ces géorèglementations à des modèles de villes et de bâtiments 3D (par exemple, BIM, CityGML et le zonage). Enfin, la thèse fournie un cadre procédurale pour vérifier automatiquement si les géorèglementations 3D viennent en conflit avec des éléments de bâtis planifiés. La preuve de faisabilité est un prototype Web basée sur une étude de cas axée sur le processus d'émission de permis de construire d'un bâtiment situé dans la ville de Melbourne, Victoria, Australie. Les géorèglementations 3D suivantes ont été modélisées et vérifiées : **1)** limites de construction en hauteur, **2)** exposition au soleil pour estimer l'efficacité énergétique du bâtiment, **3)** limite des zones d'ombrage, **4)** limites de l'impact sonore, **5)** zonage de vue, **6)** marges latérales et arrières, **7)** marges de rue (côtés et frontaux), et **8)** limites d'inondation.

Mots clés: Modélisation 3D, Règlements sur l'utilisation du territoire (géorèglementation), Planification urbaine, Administration des terres en 3D, Conflits spatio-sémantiques, Permis de construire

Abstract

The use and developments of land are regulated by utilising different mechanisms called Land-use Regulation (LuR) in various forms such as planning activities, zoning codes, permit requirements, or subdivision controls of cities. LuR makes it possible to impose or influence the use and development of land in order to achieve public policy objectives. Indeed, LuR is essential since it allows the appropriate reinforcement of resource management, contributes to the land protection and development, and provides a tangible legal framework to ensure safety and proper functioning for the harmonious access and use of land.

LuRs applies to land, where the spatial components, such as the geometry of the elements, are essential. For example, setback and height limits (i.e., the distance) or different floors' gross area should be considered when owners/developers propose a new construction on their property. These spatial components of the land, its occupied elements (e.g., building elements), or LuR itself can comprise the third dimension (i.e., depth, height, or even volume). Literature and related works show that LuR is currently mainly described in planning documents and guidelines, some of which may include 2D spatial representation (i.e., maps) or 2D cross-sections to represent the LuRs' 2D/3D extent. This method (i.e., working on textual documents and 2D plans) has significant shortcomings in understanding the LuRs' 3D extent and in decision-making (e.g., detecting potential conflicts in issuing planning/building permits). Moreover, checking LuRs' descriptions inside the textual documents is time-consuming, and subjective which might lead to erroneous decisions. Planning authorities need to have access to all information and the spatial representation that is required to assess LuRs and detect their potential conflicts. Clearly, it is generally lacking and even if 3D models of buildings (e.g., BIM designs) or cities (e.g., CityGML) have emerged, they do not incorporate the concept of LuRs.

This Ph.D. research follows qualitative engineering type of method that generally aims to propose a conceptual framework for modelling 3D LuRs geometrically as part of 3D city models and formalising geometric and semantic requirements for detecting LuRs' potential conflicts automatically to support planning authorities in the statuary planning phase. To achieve the general objective, five specific objectives are defined as: **1)** to formulate an inventory of various 3D LuRs specifying their 3D/vertical components, **2)** to propose a functional classification based on the magnitude of 3D LuRs' potential conflicts for supporting planning authorities' decision-making goals, **3)** to model LuRs in 3D and then combine them with other sources of information (e.g., BIM, city models, and zoning maps), **4)** to automate the detection of potential spatio-semantic conflicts that might arise between the modelled LuRs and physical objects like building elements, and **5)** to design and develop proof of feasibility for modelling and verifying 3D LuRs automatically.

Among more than one hundred 2D/3D reviewed LuRs, eighteen 3D LuRs are inventoried and discussed thoroughly. For each of these LuRs, the research work identifies and proposes the required information (as level of information need) by considering both geometries and semantics to combine modelled LuRs with other sources of information (e.g., BIM, CityGML, and planning maps). Finally, the thesis proposes the level of information need considering requirements to verify 3D LuRs automatically for detecting potential conflicts using analytical rules (e.g., clash detection). The proof of feasibility is a web-based prototype based on a case study located in the City of Melbourne (where planning activities are under the control of authorities in the state of Victoria, Australia) focusing on the planning permit process. The following 3D LuRs were modelled and verified: 1) building height limits, 2) energy efficiency protection, 3) overshadowing open space, 4) noise impacts, 5) overlooking, 6) side and rear setbacks, 7) street setbacks (side and front), and 8) flooding limits.

Keywords: 3D Modelling, Land-use Regulation, City and Urban Planning, 3D Land administration, Spatio-semantic conflicts, Planning Permit

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Acronyms

2D	two-dimensional
3D	three-dimensional
3D CityLuR	3D City Land-use Regulations
ABS	Australian Bureau of Statistics
AEP	Annual Exceedance Probability
BIM	Building Information Modelling
B-Rep	Boundary Representation
CityGML	City Geographic Markup Language
CSG	Constructive Solid Geometry
DELWP	Department of Environment, Land, Water & Planning
FME	Feature Manipulation Engine
IFC	International Foundation Classes
iTwin4PP	iTwin for issuing Planning Permit
LADM	Land Administration Domain Model
LiDAR	Light Detection and Ranging
LoD	Level of Detail
LODev	Level Of Development
LPPF	Local Planning Policy Framework
LuR	Land-use Regulation
NSERC	Natural Sciences and Engineering Research Council of Canada
NFPL	Nominal Flood Protection Level
PPARS	Planning Permit Activity Reporting System
RLUIPA	Religious Land Use and Institutionalized Persons Act
RRR	Rights, Restrictions, and Responsibilities
SGS	Société Générale de Surveillance
SPPF	State Planning Policy Framework

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Preface

This thesis contains five papers, three of which have been published, one accepted to be published, and one is under review as follows:

Chapter 1 contains the original content of the article: Emamgholian, S., Pouliot, J., Shojaei, D., 2020. "**Modelling Land-Use Regulation Conflicts with 3D Components to Support Issuing a Building Permit**", *in: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLIV-4/W1-2020, pp. 41–48*. Compared to the paper, few changes have been made in order to renumber sections/subsections and replace the term “this article” with “this chapter”. In addition, small corrections have been made according to the committee suggestions. Lastly, the paper’s two column format has been changed according to the thesis layout.

Chapter 2 contains the original content of the article: Emamgholian, S., Pouliot, J., Shojaei, D., 2021. "**3D CityLuR: Modelling 3D City Land-use Regulations to Support Issuing a Planning Permit**", *in: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences VIII-4/W2-2021, pp. 113–120*. Compared to the paper, few changes have been made in order to renumber sections/subsections. In addition, the term “this article” has been replaced with “this chapter”. Lastly, the paper’s two column format has been changed according to the thesis layout.

Chapter 3 contains the original content of the article: Emamgholian, S., Pouliot, J., Shojaei, D., 2021. "**3D Zoning: A Missing Piece to Link Planning Regulations with 3D Cadastre**", in: *Proceedings of the 7th International FIG 3D Cadastre Workshop*, New York, NY, USA. pp. 11–13. Compared to the paper, few changes have been made in order to renumber sections/subsections and replace the term “this article” with “this chapter”. In addition, small corrections have been made according to the committee suggestions.

Chapter 4 contains the original content of the article: Emamgholian, S., Pouliot, J., Shojaei, D., (in review) "**A Conceptual Framework for Modelling and Verifying 3D Land-use Regulation Restrictions to Support Land Administration Systems**". Submitted to Land Use Policy journal. Submission date: April 9th, 2022. Compared to the paper, few changes have been made in order to renumber sections/subsections. In addition, the term “this article” has been replaced with “this chapter”.

Chapter 5 contains the original content of the article: Emamgholian, S., Pouliot, J., Shojaei, D., 2022. " **A Web-based Planning Permit Assessment Prototype: iTwin4PP**", *in: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLVIII-4/W4-2022, pp. 37–44*. Compared to the paper, few changes have been made in order to renumber sections/subsections. In addition, the term “this article” has been replaced with “this chapter”. Lastly, the paper’s two column format has been changed according to the thesis layout.

Author Status and Contribution Saeid Emamgholian, the author of this thesis, is the first author of the five inserted articles. His contributions in all articles include investigating the state of the art, conceptualisation, developing the methodology, visualisation, and writing and revising the manuscript under the supervision of the thesis director and advisor.

Introduction

This chapter includes sections redundant with the content of other chapters. This is intentional for completeness and self-containment purposes of this chapter. Furthermore, other chapters consist of inserted articles which are presented as published or submitted.

Context

Cities are overloaded with complex multilevel developments in small proximities, causing significant challenges for managing Land-use Regulations (LuR) related to the use or developments on lands (Cann, 2018; Durham Jr and Scharffs, 2019; Selmi et al., 2017). Rapid rates of urbanisation and the increasing development of high-rises and complex structures above and below the ground surface bring new challenges for planning authorities, including the need to manage heterogeneous and possibly conflicting multilevel LuRs (Emamgholian et al., 2020a; Selmi et al., 2017). LuRs are mostly regulated based on the planning activities, zoning codes, permit requirements and conditions, and subdivision controls of cities (Durham Jr and Scharffs, 2019; Forester, 1987; Selmi et al., 2017). They are often integrated into a legal framework to control/regulate land usage and their main goal is to mediate between social space and physical space in which land developers (e.g., owners, investors, and builders) dispute the potential LuR conflicts with local residents and planning authorities (Arnold, 2006; Mayer and Somerville, 2000; Selmi et al., 2017). While LuRs might cause extra expenses for both government and citizens, they are necessary to regulate developments and restrict illegal activities, which may not be obvious to residents, contribute to the land protection, and provide an important legal framework to ensure safety and proper functioning for the harmonious access, use, and development of land (Cann, 2018; Kochan, 2014).

3D Land-use Regulations

LuRs might have two-dimensional (2D) aspects (e.g., area limits for proposed developments) or comprise 3D components for which height, depth, and volume of physical elements (or 3D LuR itself) need to be considered. In this Ph.D. thesis, 3D LuRs refer to those LuRs in which height, depth, and volume of physical objects (or LuR itself) need to be considered for being visualised or verified/checked. As an example, the planning authorities (e.g., urban planners) who issue planning permits need to verify if proposed developments respect the LuRs. This process includes checking the proposed development against 2D (e.g., gross floor area limits, car parks 2D dimensions and area limits) or 3D LuRs (e.g., height limits, setback limits such as side street, front street, side, and rear setbacks, daylight, solar access, overshadowing, overlooking, etc. as shown in Figure 0.1) (Benner et al., 2010; Olsson et al., 2018; Van Berlo et al., 2013). In such situations, after integrating various sources of information (e.g., proposed building's model, 3D city models including existing buildings, and zoning maps) the planning authorities need to check the consistency of permit applications against LuRs from various points of view such as geometry (e.g., specification of the zones where buildings can be built) and semantics (e.g., proposed building's specific elements such as windows, doors, private open spaces, etc.). They need to identify potential LuR conflicts to determine whether a planning permit can be issued.

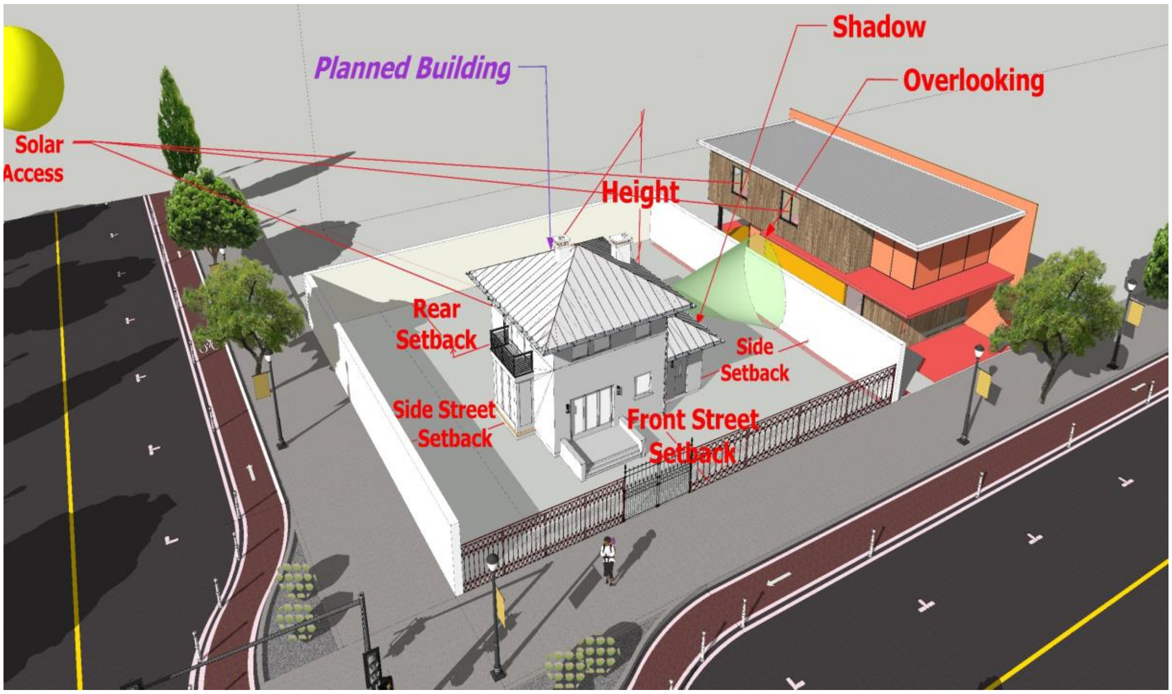


Figure 0.1 – Examples of 3D LuRs (in RED colour) for a proposed (planned) development (left building in the scene) adapted from Emamgholian et al. (2020a)

Problem Statement

Thinking in 3D - Working in 2D

Currently, LuRs are being interpreted in a planning system that is mainly based on two-dimensional (2D) maps (Benner et al., 2010; Van Berlo et al., 2013). In addition, proposed developments are represented using 2D plans, cross-sections, textual descriptions, and attributes of the building elements (e.g., height) (Benner et al., 2010; Noardo et al., 2020a; Olsson et al., 2018; Van Berlo et al., 2013). For example, a 40-storey BIM design needs requires over fifty pages of 2D plan drawings only for representing physical objects and ownership boundaries (Figure 0.2). Furthermore, LuRs are mainly textual documents open to misinterpretation that some of them might be linked to 2D planning maps.

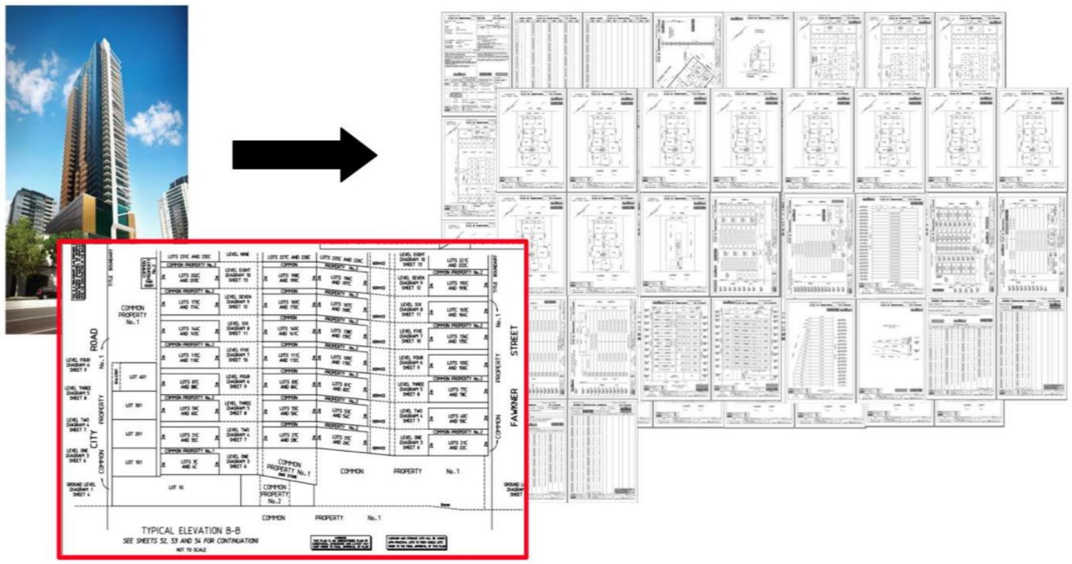


Figure 0.2 – Over 50 pages of 2D plan drawings required to represent lot boundaries for a 40-storey BIM design in Melbourne adapted from Rajabifard et al. (2014).

While LuRs in a region or state, theoretically, may be defined in a 3D space (e.g., height limits, or overlooking LuRs), their spatial representations that support their graphical interpretation by decision-makers (e.g., urban planners and land surveyors) are mainly 2D based (Olsson et al., 2018; Van Berlo et al., 2013). Accordingly, in situations where 3D components (e.g., height, depth, and volume of building elements or 3D LuRs) are involved (e.g., height limits, overlooking, flooding, or overshadowing LuRs), the use of 2D representation may result in challenges for decision-makers, and alternatively, cause erroneous permits (Benner et al., 2010; Grimmer, 2007; Hobeika et al., 2021; Noardo et al., 2022a, 2020a; Olsson et al., 2018; Van Berlo et al., 2013). As an example, in issuing planning permits in Victoria, Australia, a habitable room window, balcony, terrace, deck or patio should not cause direct views into the secluded private open spaces (or habitable room windows) of an existing dwelling within a horizontal distance of 9 metres as shown in Figure 0.3 (a). Using 2D representation and interpreting textual descriptions for verifying 3D LuRs like overlooking, often requires significant experience and expertise to clarify the 3D extent of LuRs. In this situation, assessing LuRs and detecting LuR conflicts can be challenging, time-consuming, and subjective which might lead to decisions based on the knowledge and expertise of planners or even faulty decisions (Emamgholian et al., 2020a; Grimmer, 2007; Van Berlo et al., 2013). On contrary, representing 3D LuRs like overlooking in 3D (Figure 0.3 (b)), decreases ambiguities regarding its extents and facilitates the conflict detection process extensively (Emamgholian et al., 2020a; Faucher and Nivet, 2000).

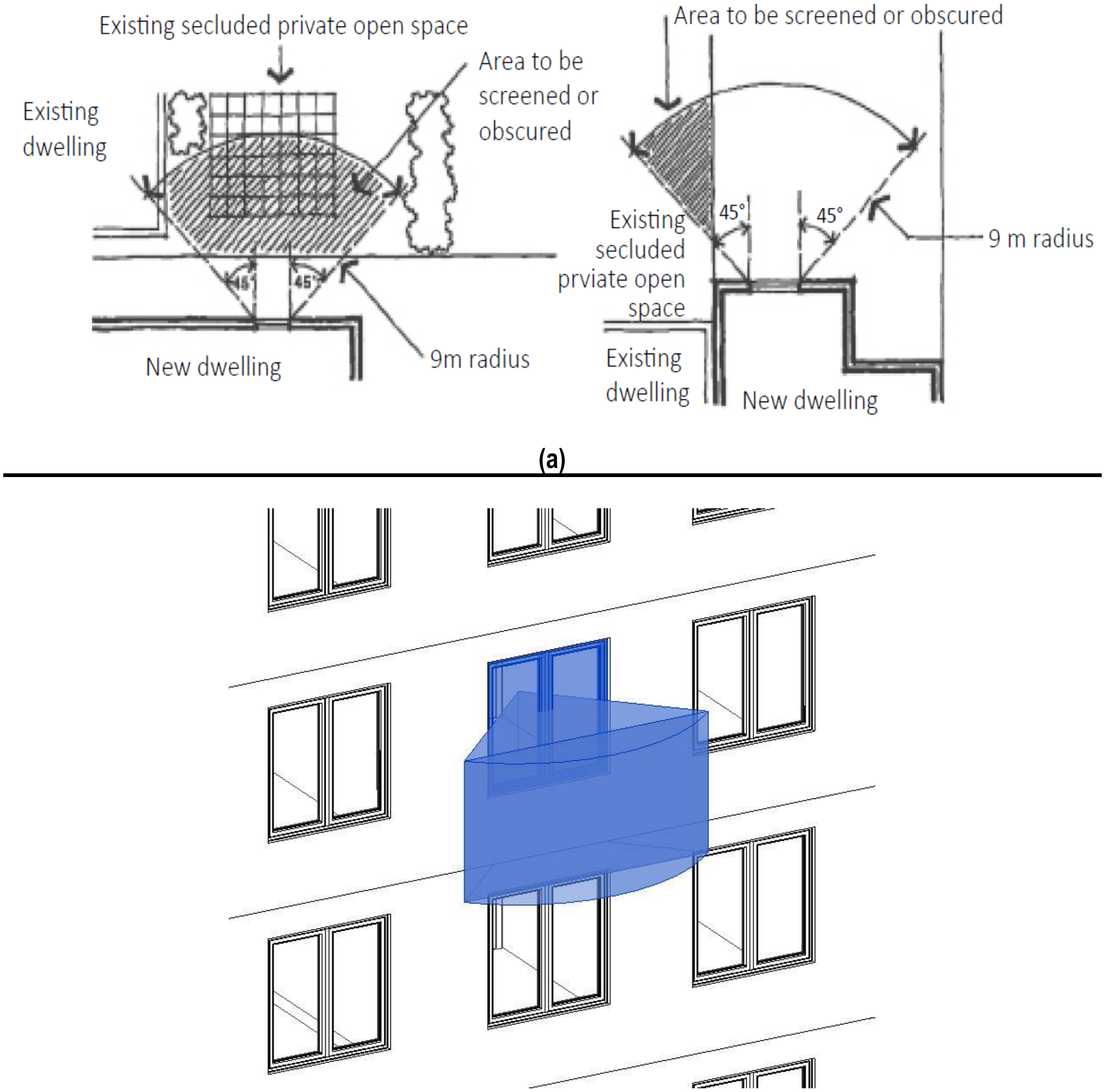


Figure 0.3 – Overlooking regulation, **a)** in 2D (adapted from Melbourne Planning Scheme Ordinance, p. 1229); and **b)** represented in 3D.

3D City Modelling and Modelling LuRs in 3D

3D city models enable integrating various geospatial information related to managing/verifying 3D LuRs such as city data in CityGML format, 3D building models (BIM and GeoBIM), city furniture, and models of transportation systems into one system through 3D geo-virtual environments (Biljecki et al., 2015; Döllner et al., 2006b, 2006a; Kolbe, 2009; Neuville et al., 2018; Noardo et al., 2020a). By considering this fact, 3D city models with the capability of 3D analyses (e.g., shadow and line of sight analyses) become suitable geo-contexts for exploring LuRs that have been rarely investigated (Döllner et al., 2006a, 2006b; Emamgholian et al., 2020a; Mohammadi, 2008).

From the modelling point of view, the emphasis of 3D city models is on urban physical objects of a city such as buildings, relief (i.e., digital terrain model), city furniture, and transportation (Kolbe, 2009; Kolbe et al., 2020) and they rarely incorporate the concept of LuRs and their potential conflicts (Batty, 2018; Benner et al., 2010; Biljecki et al., 2017; Eid et al., 2020; Emamgholian et al., 2021a; Getuli et al., 2017; Kim et al., 2016; Noardo et al., 2020a; Olsson et al., 2018; Valencia et al., 2015; Van Berlo et al., 2013). Although the third dimension will solve the drawbacks of 2D environments for exploring LuRs comprising 3D components, there is still a challenging problem. LuRs and their potential conflicts are some administrative objects that have not been fully integrated yet into 3D city models. Therefore, effective integration and visualisation of LuRs and their potential conflicts in 3D would be crucial to address the existing gap in this domain (e.g., visualising height limits or overlooking LuRs as well as their potential conflicts).

Verifying 3D LuRs

There is a wide variety of LuRs, ranging from those that need simple 2D spatial analyses to be verified (e.g., area calculation), to those that need complex 3D analyses (e.g., overshadowing and overlooking). As part of the transition from the 2D representation and verification of LuR restrictions towards a 3D digital representation and verification, not only geometric modelling of LuRs matters but also LuRs assessment considering information requirements is important since they differ based on LuRs' description and applications.

Verifying 3D LuRs can be conducted only by considering geometry (e.g., shape, orientation, and location). However, it would be limited to only verifying spatial constraints specified for geometry classes (e.g., detecting all building elements which are above the specified height limits) (Stadler and Kolbe, 2007; Wagner et al., 2013). Taking the verification of overlooking restriction as an example (Figure 0.3), habitable room windows (i.e., **geometries and semantics**) in the proposed development must not provide a direct line of sight into the existing habitable room windows/private open spaces (i.e., **geometries and semantics**) located at a distance of closer than 9 meters (i.e., **geometry**). As described in this example, to verify LuRs automatically, the model should include windows and open spaces of existing buildings (geometries and semantics) as well as their functions as attributes (e.g., habitable room window or public/private open space). These information requirements that are mostly summarised in textual planning regulatory documents and guidelines often differ based on each LuR description (Hobeika et al., 2021; Noardo et al., 2022a). This makes it difficult to reach a generic approach and procedure for assessing 3D LuRs. Therefore, there is another challenging problem formalising both geometric and semantic requirements for multiple integrated sources of information to enable assessing 3D LuRs using the same procedure and 3D spatial analysis (Hobeika et al., 2021; Noardo et al., 2022a; Olsson et al., 2018).

Research Questions

Two key research questions are defined as:

- Does the geometric 3D modelling of LuRs enable the automation of LuRs' verification process to detect potential LuR conflicts for supporting planning authorities' decision-making goals?
- What are the required geometric and semantic information to automate the 3D modelling and verification of LuRs when various sources of information (e.g., BIM, 3D city models, and planning maps/information) are integrated?

Research Hypotheses

In order to address the research questions, two hypotheses are formulated:

Hypothesis 1: It is possible to fully automate (a) 3D geometric modelling of all LuRs comprising 3D components and (b) detection of all potential LuRs' conflicts for issuing planning permits.

Hypothesis 2: To automate 3D modelling of LuRs and detecting LuR's potential conflicts, at least we need:

1) Position and shape of the 2D land parcel (i.e., cadastral boundary) and the proposed and existing 3D buildings including their composing elements under interest (e.g., walls, windows, balcony, terrace, patio, roof, private open spaces, rooftop solar panels), and
2) For all possible LuRs,
   2A. Spatial extent of LuR restrictions (e.g., distance, angle), 2D planning zones (polygons) including overlays and public open spaces;
   2B. Semantic information such as LuR name, name and category of planning zones (e.g., capital city zone/general residential zone/street/railway line), and category of proposed buildings (residential/commercial); and
3) Contextual information for specific LuRs such as specified dates and times for checking overshadowing.

Research Objectives

General Objective

The general objective of this research is to design a conceptual framework based on planning authorities' needs that formalises required geometric and semantic information in different sources of 3D spatial information (e.g., BIM, city models, and planning maps/information) for modelling LuRs in 3D and detecting LuRs' potential spatio-semantic conflicts.

Specific Objectives

The general objective can be met by achieving the following specific objectives:

1. To formulate an inventory of various 3D LuRs specifying their 3D/vertical components;

2. To propose a functional classification based on the magnitude of 3D LuRs' potential conflicts for supporting planning authorities' decision-making goals;
3. To model LuRs in 3D automatically and then combine them with other sources of information (e.g., BIM, city models, and zoning maps) to support automatic conflict detection in planning approval and building subdivision processes;
4. To identify the level of information need (i.e., geometries and semantics) for automatically detecting potential spatio-semantic conflicts that might arise between the modelled LuRs and physical objects like building elements;
5. To design and develop a web-based planning permit assessment prototype (as proof of feasibility) for modelling and verifying 3D LuRs automatically in the process of issuing planning permits.

Methodology

This research follows an engineering-type of methodology by identifying the research problems, proposing a solution to deal with the problems, and checking the validity of the proposed solution (Kothari, 2004; Tang, 2020). To address the encountered problems, this thesis proposes a conceptual framework formalising the concepts in three stages that are essential for modelling and verifying 3D LuRs in order to detect LuRs' potential spatio-semantic conflicts automatically. These concepts are LuRs comprising 3D components and their key modelling parameters, the physical/administrative objects that can be impacted by these LuRs, and the notion of 3D LuR conflicts (geometric and semantic). Finally, the feasibility of the proposed conceptual framework will be tested and evaluated by designing and developing a web-based planning permit assessment prototype for modelling and verifying 3D LuRs automatically in the process of issuing planning permits.

In this research, an exploratory mixed method integrating both qualitative and quantitative methods has been utilised to identify planning authorities' requirements, which is stronger than relying on a single qualitative or quantitative method (Borrego et al., 2009; Kothari, 2004). The exploratory mixed method starts with a qualitative phase and follows by a quantitative phase. The qualitative phase in this thesis includes literature review, meetings (with planning authorities), use cases (i.e., planning permit and building subdivision), and case studies (i.e., the City of Melbourne in Victoria, Australia). This qualitative phase follows by a quantitative phase (i.e., prototyping and validating the results inside iTwin platform) in which a proposed building will be evaluated within the prototype to match the number of detected conflicts by the prototype with a pre-assessed number of potential conflicts. The selected use-cases, planning permits and building subdivision processes, were identified as the most useful use cases for further investigation in the literature based on users' needs in which various 3D LuRs can be applied (Benner et al., 2010; Hobeika et al., 2021; Noardo et al., 2020a, 2019; Olsson et al., 2018; Shin et al., 2022; Van Berlo et al., 2013).

In order to address the research objectives, the approach is elaborated in three phases as follows:

Phase 1: Inventory of LuRs comprising 3D components, and classification of potential LuR conflicts.

In this phase, the theoretical background of the research was established. From the literature review and case studies, an inventory of LuRs with a focus on planning permits and building subdivision processes has been proposed. 3D LuRs and their spatio-semantic characteristics have been highlighted to help us to understand the notion of various 3D LuRs and their role in controlling land usage and development. In addition, two functional classifications of potential conflicts in a planning permit process from two points of view (i.e., data integration process and magnitude of LuR conflicts) have been proposed. These results have been placed in the context of 3D city models that integrate LuR information. The results of this phase give us a clear impression of 3D LuRs, their characteristics, and potential conflicts in the domain of planning approval and building subdivision processes.

Phase 2: Design and develop a three-stage conceptual framework that formalises spatio-semantic requirements applied to 3D spatial information for modelling and verifying 3D LuRs automatically.

This phase starts with focusing on understanding planning authorities' needs at a greater level for automating the process of assessing LuRs automatically. For this purpose, there would be several meetings with the experts in DELWP[1] (which is the responsible authority for assessing development applications containing a total gross floor area of more than 25,000 square metres in the state of Victoria). This will mainly help us to better identify the requirements for proposing the conceptual framework. For modelling and verifying 3D LuRs automatically, the framework organises all the IFC required classes/concepts, CityGML required classes/concepts, and most importantly, the planning and zoning requirements.

The framework's first stage, focusing on modelling 3D LuRs geometrically, proposes the modelling key parameters representing their extent (mainly from planning scheme ordinance and planning documents). Although converting the LuRs' description to a machine-readable format is not the focus of this study, it can be applied in this stage to extract some of the key parameters automatically. This stage then aims to propose a geometric modelling approach based on the identified key parameters to model 3D LuRs automatically. The second stage, focusing on combining the modelled LuRs with other sources of information automatically, proposes the level of information need (i.e., geometries and semantics) for combining modelled 3D LuRs with other sources of information such as BIM design of proposed developments, zoning maps, and 3D city models including existing buildings (e.g., in CityGML format). Finally, the last stage, namely conflict detection with a

[1] https://www.delwp.vic.gov.au/

focus on automating 3D LuRs' conflict detection, proposes the level of information need (i.e., geometries and semantics) for detecting their potential spatio-semantic conflicts automatically that might arise between LuRs and physical objects like building elements. Twelve 3D LuRs are addressed and discussed thoroughly including **1)** height Limits, **2)** side and rear setbacks, **3)** street setbacks, **4)** north-facing windows, **5)** energy efficiency protection, **6)** overshadowing open space, **7)** solar access to open space, **8)** daylight to existing windows, **9)** daylight to new windows, **10)** overlooking, **11)** noise Impacts, and **12)** flooding limits.

This framework, as the main objective of this research, organises and proposes mandatory principles and a generic procedure for managing/interacting with 3D LuRs leading to automating the 3D modelling and conflict detection of 3D LuRs. It should be noted that the BIM-GIS integration challenges (e.g., converting IFC to CityGML or vice versa) are not the focus of this research work, and it is assumed that this part is currently conducted.

Phase 3: Design and develop a web-based planning permit assessment prototype for modelling and verifying 3D LuRs automatically.

In the last phase of this research, a web-based planning permit assessment prototype has been designed and developed to demonstrate the feasibility of the proposed framework to automate the process of modelling and verifying 3D LuRs. It is developed based on a specific use-case of issuing planning permits in the city of Melbourne in Victoria, Australia, as a case study. This prototype has been developed by coding within the iTwin platform using JavaScript and ReactJS to address specific requirements as follows:

- Loading different data sources (e.g., zoning base map and BIM design of a high-rise building as a proposed building in IFC format or RVT) into iTwin;
- Modelling and visualising 3D LuRs geometrically including **1)** height limits, **2)** energy efficiency protection, **3)** overshadowing open space, **4)** noise impacts, **5)** overlooking, **6)** side and rear setbacks, **7)** street setbacks (side and front), and **8)** flooding limits;
- Combining 3D LuRs with the proposed and adjoining buildings;
- Verifying 3D LuRs by a set of analytical rules based on the identified required geometric and semantic information (3D LuRs that have been tested and evaluated include: **1)** height limits, **2)** energy efficiency protection, **3)** overshadowing open space, **4)** noise impacts, **5)** overlooking);
- Detecting and locating the potential conflicts among LuRs and physical objects like building elements automatically; and
- Visualising the conflicts (e.g., a complete report of validation checks).

This phase is about the application, evaluation, and validity, which is more related to users and experiments and addresses the last specific objective of this research work.

Contributions of this Work

The main contributions of this research include:

- The first attempt to organise and propose a generic conceptual framework for managing/interacting with 3D LuRs that leads to detecting LuRs' potential conflicts automatically;
- The first attempt to model LuRs in 3D through specifying LuRs' modelling parameters and a geometric modelling approach that best fits with the parameters to model LuRs automatically;
- The first attempt to formalise the level of information need (considering both geometries and semantics) for modelling LuRs in 3D and combining them with other sources of information (e.g., BIM, city models, and planning maps/information) for the specific purpose of issuing planning permits;
- The first proposal for enriching 3D zoning with 3D representation of 3D LuRs to support land administration systems;
- The first attempt to reach a generic approach for detecting potential 3D LuRs conflicts by formalising the level of information need (considering both geometries and semantics) beyond BIM applications;
- An innovative web-based planning permit assessment prototype (as proof of feasibility) for modelling and verifying 3D LuRs automatically.

Thesis Organisation

The structure of the thesis is organised as follows:

This chapter has been focused on introducing the research context and the motivations of the thesis. In detail, the problem statement of the research context, the research questions, hypotheses, general and specific objectives, proposed methodological approach, and the contributions of this research have been described.

Chapter 1 focuses on inventorying LuRs comprising 3D components, and classification of potential LuR conflicts by considering the conflicts' magnitude in the data processing and their impacts on a decision-making process. This chapter is aligned with the first phase and addresses the first and second specific objectives of this thesis. After validating the proposed classification with planning authorities at DELWP, the classification will be further updated in Chapter 4, section 4.6.3.1.

Chapter 2 is dedicated to elaborating and presenting how 3D LuRs can be modelled in 3D (called 3D CityLuR) and then combined with other sources of information (e.g., BIM, city models, and zoning maps) to support detecting LuRs' potential conflicts in a later stage. Then, **Chapter 3** opens a discussion regarding enriching 3D zoning with the 3D representation of LuR restrictions to support land administration and 3D cadastre. These chapters address the third and fourth specific objectives (modelling part) of this research and are aligned with the first part of the second phase of this thesis.

Chapter 4 focuses mainly on detecting potential LuR spatio-semantic conflicts by utilising 3D spatial analyses in a later stage. For this purpose, it proposes a conceptual framework that formalises required geometric and semantic information (as the level of information need) in different sources of 3D spatial information (e.g., BIM, city models, and planning maps/information). This chapter is aligned with the second phase and addresses the fourth specific objective (conflict detection part) and the general objective of this research.

Chapter 5 is devoted to designing and developing a web-based planning permit assessment prototype (as proof of feasibility) for issuing planning permits automatically. This chapter is aligned with the last phase (i.e., phase 3) of this research and addresses the last specific objective of this research.

Finally, the last chapter (i.e., **Conclusions and Perspectives**) concludes the thesis with the main findings and directions for future research. The chapter also reviews the research hypotheses and objectives and validates them based on the main findings of this study.

Chapter 1 – Modelling Land-Use Regulation Conflicts with 3D Components to Support Issuing a Building Permit

This chapter focuses on exploring LuRs to inventory LuRs comprising 3D components and proposing two functional classifications of potential conflicts in a building permit process from two points of view (i.e., data integration process, and magnitude of LuR conflicts). The main contributions of this chapter are: (1) an original inventory and classification of LuRs comprising 3D components, and (2) a functional classification of LuRs' conflicts in a building permit process. It should be noted that **the classification based on the magnitude of LuR conflicts in this chapter has been revised during the progress of writing the thesis and the reader should refer to Chapter 4, section 4.5.5, to get the latest proposed classification of 3D LuRs' conflicts.**

This chapter is the original content of the following paper:

> Emamgholian, S., Pouliot, J., Shojaei, D., 2020. "Modelling Land-Use Regulation Conflicts with 3D Components to Support Issuing a Building Permit", in: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLIV-4/W1-2020*, pp. 41–48, https://doi.org/10.5194/isprs-archives-XLIV-4-W1-2020-41-2020.

1.1 Résumé

Les villes sont confrontées à des défis importants en raison de la croissance démographique et du développement massif de tours et de structures complexes au-dessus et au-dessous de la surface du sol. À cet égard, il est nécessaire pour les villes de disposer d'un cadre de géorèglementations efficace en matière d'utilisation du territoire. En examinant les pratiques actuelles de traitement des données spatiales lors de l'émission de permis de construire, on constate que dans de nombreux cas, le bâtiment prévu est dessiné sur des plans en 2D avec des coupes transversales pour représenter leurs dimensions en 3D. Dans les développements complexes à plusieurs niveaux, cette méthode présente des lacunes importantes, comme la nécessité de gérer de nombreux plans et sections, et l'incertitude des décisions, plus particulièrement lors de la vérification des règles régissant l'utilisation du territoire comprenant des éléments 3D (par exemple, les limites de construction en hauteur, les objets en surplomb, les droits solaires). Afin d'appuyer le processus d'émission de permis de construire et de progresser vers l'établissement de villes intelligentes en 3D, ce chapitre présente un inventaire des géorèglementations d'utilisation du territoire ayant des composantes 3D et une classification fonctionnelle des conflits pouvant survenir avec le bâtiment planifié. La classification des conflits s'appuie sur deux éléments décisionnels soit le processus d'intégration des données et le degré d'importance des conflits

constatés. Ces résultats sont placés dans le contexte des modèles de ville 3D en leur associant des informations sur la géorèglementation de l'utilisation du territoire.

1.2 Abstract

Cities are facing important challenges due to population growth and massive development of high-rises and complex structures above and below the ground surface. In that respect, having an efficient land-use regulation framework in force is necessary for cities. In investigating current practices for processing spatial data when issuing building permits, in many cases, the planned building is drawn on 2D plans with cross-sections to represent their 3D dimensions. In complex multilevel developments, this method has significant shortcomings like the requirement of managing numerous plans and sections, and uncertainty in decisions more specifically when checking land-use regulations comprising 3D components (e.g., height limits, overhanging objects, solar rights). In order to support issuing a building permit and moving towards the establishment of 3D smart cities, this chapter presents an inventory for land-use regulations with 3D components and functional classification of their possible conflicts. Two functional classifications of possible conflicts in a building permit process from two points of view (i.e., data integration process, and magnitude of land-use regulation conflicts) are proposed. These results are placed in the context of having 3D city models that integrate land-use regulation information.

1.3 Introduction

1.3.1 Context

Rapid rates of urbanisation and the increasing development of buildings and high-rises bring new challenges for city authorities, including the need to manage heterogeneous and possibly conflicting multilevel land-use regulations. As an example, the experts who issue building permits in a municipality need to verify if new proposed constructions respect the regulations for building height, setbacks (i.e., side street, front street, side, and rear setbacks), daylight, solar access, shadowing, overlooking, etc. This process includes checking the proposed application against planning and building regulations (Benner et al., 2010; Noardo et al., 2020a; Olsson et al., 2018; Van Berlo et al., 2013). In such situation, they need to integrate various information to check the consistency of permit applications with land-use regulations from various points of view such as geometry (e.g., specification of the zones where buildings are allowed to be built) and semantic (e.g., specification of maximum height or minimum setback distance) (Stadler and Kolbe, 2007). Finally, they need to identify possible conflicts to determine if the building permit should be approved or not.

The majority of land-use regulations are defined based on the planning activities, zoning codes, permit requirements and conditions, and subdivision controls of cities (Durham Jr and Scharffs, 2019; Forester, 1987; Selmi et al., 2017). Land-use regulation, on one hand, restricts illegal activities, which may not be obvious to residents, and on the other hand, causes extra expenses (Cann, 2018; Kochan, 2014). It is often integrated into a legal framework to control land usage and its main goal is to mediate between social space and physical space in which developers (including owners, investors, builders, etc.) often dispute about spatial conflicts of these regulations with local residents and municipalities (Arnold, 2006; Mayer and Somerville, 2000; Selmi et al., 2017). According to Gresch and Smith (1985) "*spatial conflicts are overt public disagreements about some actual or proposed use of land or property development*".

1.3.2 Problem Statement

1.3.2.1 Thinking in 3D, Working in 2D

Currently, land-use regulations are interpreted in a planning system which is mainly based on 2D maps (Benner et al., 2010; Van Berlo et al., 2013). In addition, proposed buildings are represented using two-dimensional (2D) plans, cross-sections, textual descriptions, and attributes of the building elements (e.g., height) (Benner et al., 2010; Noardo et al., 2020a; Olsson et al., 2018; Van Berlo et al., 2013). In addition, land-use regulations are mainly textual documents, open to interpretation, that some of them might be linked to 2D planning maps.

While the land-use regulations in a region or state, theoretically, may be defined in a 3D space (e.g., maximum allowed height, or overlooking regulations), the spatial representations that support their graphical interpretation by decision-makers (e.g., land lawyers, urban planners, and land surveyors) are mainly 2D based (Olsson et al., 2018; Van Berlo et al., 2013). Accordingly, in situations where 3D components (e.g., height, depth, and volume of building elements or 3D land-use regulations) are involved, the use of 2D representation may result in challenges for decision-makers (e.g., in checking overshadowing regulation), and alternatively cause erroneous building permits. For example, Grimmer (2007) reviews a real case where a building was almost built with a higher allowable height according to an erroneously granted permit. In addition, due to the complexity of multi-level developments, numerous plans and sections are required and these are difficult to manually check and finding land-use regulation conflicts can be very difficult.

1.3.2.2 3D City Modelling and Land-use Regulations

3D city models are emerging solutions in the administration of cities that allow integrating various geospatial information such as CityGML models, 3D building models (BIM), and models of transportation systems into one system through 3D geo-virtual environments (Biljecki et al., 2015; Döllner et al., 2006b, 2006a; Kolbe, 2009; Neuville et al., 2018; Noardo et al., 2019). By considering this characteristic, 3D city models with the capability of 3D analyses (e.g., shadow and line of sight analyses) become suitable geo-context for exploring land-use regulations that rarely investigated (Döllner et al., 2006a, 2006b; Mohammadi, 2008).

Although the third dimension will solve the drawbacks of 2D environments for exploring land-use regulations that have 3D components, there is still a challenging problem. Land-use regulations and their potential conflicts are some administrative objects that have not been fully integrated yet into 3D city models. Therefore, effective integration and visualisation of land-use regulations and their possible conflicts would be a crucial problem in this domain (e.g., visualising building height or overlooking regulation as well as their possible conflict).

1.3.3 Objectives

A research project has been recently started in collaboration between Université Laval (Centre for Research in Geospatial Data and Intelligence) and the University of Melbourne (Centre for SDIs and Land Administration) to precisely address the problem of detecting the geometric and semantic conflicts among land-use regulations with 3D components by considering intended users and their needs. In this context, the first hypothesis of this work is as follows: The decision-maker needs to have access to pre-organised data that will aggregate original 3D data (i.e., physical objects and land-use regulations) in a form that enables the ranking of conflicts. Consequently, as a preliminary phase of this project, the objective of this chapter is to propose:

(1) An inventory of land-use regulations comprising 3D components by considering their semantic aspects.

(2) A functional classification of potential land-use regulation conflicts by considering the conflicts' magnitude in the data processing of a building permit issuance and their impacts on a decision-making process.

In this chapter, 3D components refer to any information that is required to inspect the space in 3D. The 3D space may contain physical objects like building elements that integrate the height, depth, or volume and/or administrative objects like land-use regulations that consider the third dimension like building height regulation.

1.3.4 Methodology

The approach consists in describing, interpreting, and contextualising the concepts related to 3D land-use regulations for addressing the problems. First, a comprehensive literature review is conducted (Section 1.4) and an inventory of land-use regulations comprising 3D components by considering their semantic aspects is proposed (Section 1.5.1). Second, potential land-use regulation conflicts are classified on the basis of common descriptive characteristics, and two classifications according to attributes are proposed in the domain of planning permit (Section 1.5.2).

In order to bring together consistent results and reduce the extent of the investigation, the analysis focus on the building permit process. A building permit process is a valuable case study that involves a variety of land-use regulations for which 3D space is considered. Melbourne city area in Victoria, Australia, is selected as a case study, which helps understand the current practice and existing issues and challenges. Figure 1.1 illustrates a number of land-use regulations in a building permit process by using SketchUp 3D warehouse samples.

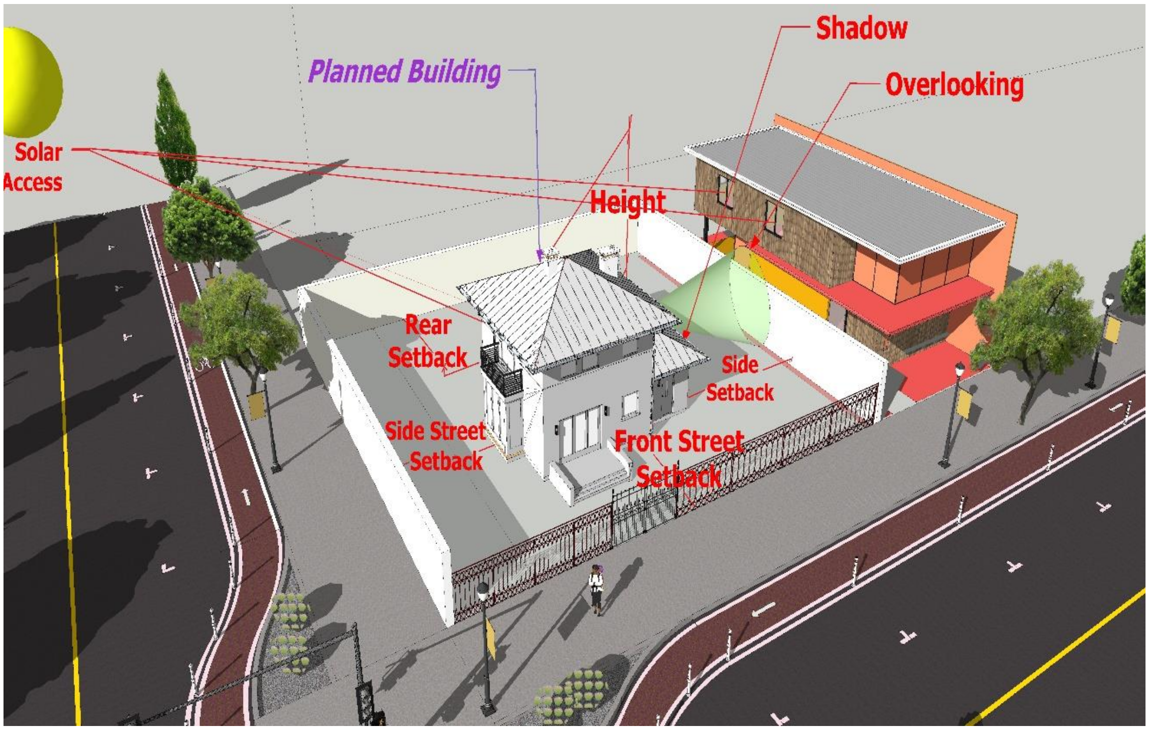


Figure 1.1 – Examples of land-use regulations (in RED colour) for a new proposed (planned) building (left building in the scene)

1.4 Related Studies

This section reviews related studies in the classification of land-use regulations, classification of possible conflicts in a data integration process as well as previous works related to issuing a building permit.

1.4.1 Land-use Regulations (in Building Permit Process)

Typically, land-use regulation behaves as a sub-category of another area of law, such as constitutional law, environmental law, administrative law, or local government law (Arnold, 2006; Salsich and Tryniecki, 1998; Selmi et al., 2017). We can highlight one of its definition in the "Religious Land Use and Institutionalised Persons Act" (RLUIPA) as: "*Zoning or land-marking law, or the application of such a law, that limits or restricts a claimant's use or development of land (including a structure affixed to land), if the claimant has an ownership, leasehold, easement, servitude, or other property interest in the regulated land or a contract or option to acquire such an interest*".

Benner et al. (2010) argue that for the building permit process, both geometric and semantic aspects of the data need to be considered. They developed a prototype for checking some regulations such as site occupancy index, floor space ratio, the building height based on the number of storeys, and the roof type, roof shape, and the direction of the ridge. To this purpose, they consider the integration of three kinds of the data including BIM model in IFC format, the city map in CityGML format for existing building surrounding the proposed (planned) construction, and legally binding land-use plan (a German standard) in the XplanGML format in which the objects are represented as 2D geometries with corresponding attributes. They suggest converting the BIM data to CityGML format and then importing the building data to a city model where the rule checking will be carried out.

Van Berlo et al. (2013) converted the spatial planning map into 3D building objects by using the maximum allowed building height value given in the regulations. The main focus of their work was on investigating four regulations including the maximum allowed building volume, the maximum percentage of the built area on the site, the maximum allowed noise value on the façade of the buildings, and if protected cultural heritage in the underground is not harmed by the designs. In their work, the rule checking is performed in a BIM environment in which the architects can conduct their own rule checks before submitting the application for the building approval (e.g., using software such as Solibri Model Checker).

Noardo et al. (2020a) proposed a GeoBIM workflow (as part of GeoBIM project) for issuing a building permit. The workflow has several steps including reading and using 3D city model and regulations that can be read by a computer, checking the BIM's validity, semantics and geo-referencing, conversion of BIM to CityGML, analysing the integrated information for checking the picked city regulations, and building permit issuing. In addition, in order to find the common regulation checks amongst the municipalities of participating project partners, they proposed a classification by considering 3D spatial and semantic aspects of these regulations. They classified a number of common land-use regulation checks in European countries as:

- Zoning and dimensions (e.g., maximum height and distances from other buildings);
- Parking availability;
- The impact of building on environment and the impact of environment on building (e.g., overshadowing and air quality).

Olsson et al. (2018) proposed an approach to automate the process of issuing a building permit for three specific regulations including building height, building footprint area, and one visual criterion. Their study is based on the approach of importing the BIM model of new buildings, into a geospatial data environment in which municipalities carry out the legal check of the regulations. In addition, they proposed a classification of the property criteria in Swedish detailed development plans in which they classified the regulations into three main classes by taking to account the main available source of datasets (i.e., BIM, geospatial, and integrated BIM and geospatial data). The three classes are as follows:

- Quantitative regulations, which can be checked automatically (e.g., building heights);
- Qualitative regulations, which are difficult to be checked automatically (e.g., maintenance of specific historical and artistic values); and
- Visual regulations, which can be supported digitally (e.g., configuration of windows).

However, they did not provide any details about the investigated regulations considered in their classification. They just presented the final percentage of regulations in each class.

1.4.2 Land-use Regulation Conflicts

Despite the extensive research carried out in the last decade in the field of land-use regulation and building permit issuance (Benner et al., 2010; Noardo et al., 2020a, 2019; Olsson et al., 2018; Van Berlo et al., 2013), there is a lack of research with a focus on the investigation about land-use regulation conflicts. For this reason, we decided to extend our literature review to spatio-semantic data conflicts. For instance, Fileto (2001) proposed a classification for conflicts that may arise by having two or more sources of information in the context of relational databases. He investigated these conflicts from two orthogonal aspects as follows.

- Abstraction level
  - Data instance conflicts (e.g., conflicts in units)
  - Schema conflicts (e.g., an attribute in one relational schema that is modelled as a relation in another relational schema)
  - Data model conflicts (e.g., one database designed according to the relational model while the other is object-oriented)
- Representation and interpretation level
  - Syntactic conflicts (i.e., discrepancies in the representation of data)
  - Semantic conflicts

Wang and Hu (2009) described possible conflicts in a spatial data integration process and proposed a number of possible solutions in dealing with these conflicts. They classified the potential conflicts between different spatial data sources into three main classes including:

- System conflicts (when technical aspects such as hardware platforms are different);
- Syntax conflicts (mainly reflected on data models);
- Semantic conflicts (conflicts in the meaning, interpretation, or use of the data).

1.4.3 Clash Detection in Building Information Modelling (BIM)

3D modelling and BIM, as a part of the literature review, were investigated, and the current approach of clash classification in BIM seemed quite applicable for the assessment of land-use regulation conflicts. For this reason, this section briefly explains the notion of “clash” as a special kind of spatial conflicts (Eastman et al., 2008; Matejka and Sabart, 2018; Mehrbod et al., 2019; Reddy, 2011; Sampaio and Berdeja, 2017; Webster, 1971). Subsequently, section (1.5.2.2) will explain its correspondence with our proposed classification for land-use regulation conflicts.

Generally, clashes are only applicable to the BIM data, and they cannot be applied in a data integration process in which there are other kinds of models such as geospatial data (Eastman et al., 2008; Sampaio and Berdeja, 2017; Webster, 1971). However, it can be considered as a part of a data integration process when several parts of a BIM data are designed by different designers or architects and need to be integrated to create the whole BIM data (that again it is only related to BIM data).

Matejka and Sabart (2018) categorise clashes in four types in the construction process including hard clashes, soft clashes, 4D clashes, and animated clashes (clashes of animated objects). The last two clashes are related to the construction phase, and they are out of the scope of this chapter.

- Hard clashes refer to only geometrical issues in which two or more building elements intersect or overlap (Reddy, 2011). They can be costly to fix if missed in the design process (e.g., the collision of piping and a beam (column) as shown in Figure 1.2(a)).
- Soft clashes are the clashes between one entity and another's buffer area, which is set around it (Reddy, 2011). As an example, Figure 1.2(b) illustrates a soft clash in which a column is placed right in front of a door.

(a) (b)

Figure 1.2 – **a)** Hard clash between a pipe and a beam; **b)** Soft clash between a door and a beam.

- 4D clashes happen due to low quality in project management and occur during the construction phase (i.e., time is considered). The conflict between the crane and scaffolding during the construction phase is an example of this clash.
- Finally, animated clashes have a dynamic characteristic such as people walking on stairs and through corridors, or components that require manipulation space (e.g., moving a virtual person to inspect the correction of specified measurements through corridors and stairs). These collisions are more similar to soft clashes with the differences in using a dynamic buffer instead of the static one

Some other researchers have addressed the design conflict that occurs when a building component conflicts with another building component in BIM designs (Akinci et al., 2002; Wu and Chiu, 2010). The conflicts are related to the design phase when a building component conflicts with another (e.g., gaps or slivers). One alternative to identify design conflicts, as well as clashes, is to define some validation rules in order to reduce the potential issues (Ledoux, 2018; Shojaei et al., 2017). For example, in the city of Melbourne, the first phase of cadastral applications is to check the plan by several validation rules to verify its consistency in terms of design conflicts (Shojaei et al., 2017).

1.5 Modelling 3D Land-use Regulations

This section proposes the main contributions of this chapter, which are an inventory of land-use regulations comprising 3D components and functional classification of their possible conflicts when representing them in 3D (based on the magnitude of their impacts on issuing building permits). These two results seek to extend our understanding of any specific land-use regulation conflict situation and facilitate the decision-making process for issuing building permits in our case for the intended users.

1.5.1 Inventory of Land-use Regulations Comprising 3D Components

The inventory identifies the land-use regulations (subject to planning and building approvals) that comprise 3D components and distinguish semantic aspects of regulations. In this part, the most common land-use regulations that need to be checked for issuing a building permit (as a use-case) are reviewed. These regulations are based on "Building Regulations 2018, Authorised Version No. 001, S.R. No. 38/2018" of the Victorian Government[2] in Australia. Based on the work of Noardo et al. (2020), Tables 1.1, 1.2, and 1.3 show our proposed inventory of land-use regulations. The main characteristics considered in this inventory include having 3D components (e.g., height, depth, and volume of building elements or 3D land-use regulations) and semantic aspects. Semantic aspects will mainly facilitate understanding of potential semantic conflicts for proposed (planned) buildings in a planning permit process. For instance, window of a habitable room in a proposed (planned) building should be distinguishable from the other windows. In order to identify land-use regulations comprising 3D components, more than 100 regulations (2D & 3D) that should be considered in the planning system were reviewed and classified based on their characteristics into four main classes as:

1) **Zoning and dimensioning:** If the regulation has some rules and criteria, which are the same for its entire zone (i.e., they differ based on the characteristics of their zone), or they are related to dimensions, they will be in this category. Common regulations in this class are as follows:

- Site Coverage: Regulation related to that part of the proposed lot that is covered by buildings. It is often expressed as a percentage of the area of the land or densification level.
- Building Height: The vertical distance between ground level and top of the roof.
- Street Setbacks (Max & Min): Regulation related to the minimum and maximum distance from the boundary of building to the street.
- Side and Rear Setbacks: It is related to the setback from a side or rear boundary of the building (those sides of boundaries that are not adjacent to streets).
- Private Open Space: Regulation related to an unroofed area of land, or a deck, terrace, patio, balcony, pergola, veranda, gazebo, swimming pool, or spa.
- Walls and Carports on Boundaries: Regulation related to a wall or carport of a building constructed on its side or rear boundary.
- Car Parking Spaces: Number of car parking spaces, underground and in covered areas.

[2] http://www.legislation.vic.gov.au

Table 1.1 – summarises these regulations by describing their 3D components and semantic aspects.

Table 1.1 – Zoning and dimensioning regulations

Reg. Name	3D Components	Semantic Aspects
Site Coverage	• Different vertical levels of buildings	• Information related to swimming pools or spas, unroofed terraces, unroofed patios, unroofed decks, and pergolas • Width of eaves, fascia, and gutters
Building Height	• Height of building elements	• Type of entities (e.g., the height of ventilation and air conditioning, entrance storey, etc.)
Street Setbacks (Side and Rear)	• Overhanging objects like balconies	• Type of street setbacks (i.e., side or rear) • Type of streets (i.e., narrow, medium, and wide)
Side and Rear Setbacks	• Overhanging objects like balconies	• Type of setbacks (i.e., side or rear) • Type of boundaries
Private Open Space	• Overhanging objects	• Information related to a deck, terrace, patio, balcony, pergola, veranda, gazebo, swimming pool or spa
Walls and Carports on Boundaries	• The height of walls	• Type of walls • Type of boundaries (e.g., side and rear)
Car Parking Spaces	• Underground spaces	• Functionality of car parking spaces (e.g., bikes, cars).

2) **Lights and shadows:** If the regulation is related to sun or skylight and shadow, it will be in this category. Common regulations in this class are as follows:

- Daylight to Existing Habitable Room Windows: The natural light of the day for existing buildings adjoining proposed (planned) building.
- Solar Access to Existing north-facing Habitable Room Windows: Based on Victorian government definition, "north-facing window means a window of a room that has an axis perpendicular to its surface oriented true north 20° west to true north 30° east".
- Overshadowing of Recreational Private Open Space: Recreational private open spaces are generally intended for outdoor recreation activities.
- Daylight to Habitable Room Windows: The natural light of the day for a proposed (planned) building.

Table 1.2 summarises the aforementioned regulations by describing their 3D component and semantic aspects.

Table 1.2 – Lights and shadows regulations

Reg. Name	3D Components	Semantic Aspects
Daylight to Existing Habitable Room Windows	• The height of adjoining walls	• Type of windows
Solar Access to Existing north-facing Habitable Room Windows	• Building height	• Type of windows
Overshadowing of Recreational Private Open Space	• Height of proposed (planned) building • Height of adjoining buildings	• Type of open spaces
Daylight to Habitable Room Windows	• Height of building elements in room's front outdoor space	• Information related to veranda, porch, deck or balcony, and carports

3) **Viewshed:** It is related to the line of sight.

- Overlooking: A bedroom on a proposed (planned) building must not provide a direct line of sight to adjoining bedrooms in neighbouring buildings.
- Projections beyond Street Alignment: Street alignment means the line between a street and an allotment.

Table 1.3 summarises these two regulations by describing their 3D component and semantic aspects.

Table 1.3 – Viewshed regulations

Reg. Name	3D Components	Semantic Aspects
Overlooking	• Height of the window of habitable room in planned / existing buildings • Height of the level of habitable room	• Type of windows • Information related to a balcony, a terrace, a deck or a patio • Type of open spaces
Projections beyond Street Alignment	• Overhanging objects like balconies	• Information related to the type of entities (Balconies, Verandas, etc.) • Type of streets (i.e. Narrow, Medium, and Wide)

4) **Uncommon regulations:** Those regulations that are very specific in a jurisdiction, and do not belong to the previous classes. For example, there is a number of regulations for "Fences" comprising 3D components such as front fence height and fence setbacks from side and rear boundaries.

1.5.2 Land-use Regulation Conflicts

After exploring different land-use regulations, and in order to enhance the current decision-making process for urban planners in a situation where many land-use regulations are involved, this section presents the possible conflicts that may arise in a building permit process. To this purpose, the conflicts are reviewed by considering two aspects. First, we have traced the land-use regulation conflicts based on the traditional way of examining a spatial data integration process including spatial, semantic, and temporal conflicts (Fileto, 2001; Mohammadi, 2008; Wang and Hu, 2009). This classification aims to group land-use regulation conflicts by considering the heterogeneity of the sources of data. Second, the magnitude of land-use regulation conflicts that influences the decision of issuing or rejecting a building permit is investigated.

1.5.2.1 Classification of Land-use Regulation Conflicts

This classification will mainly help the users in a data integration process in order to know several conflicts that may arise by the integration of different datasets in a building permit process. The proposed classification includes three main classes named spatial (geometric and topologic sub-classes), semantic (syntactic, structural or schematic, and sense or meaning sub-classes), and temporal conflicts. Table 1.4 summarises the proposed classification by bringing several examples in a building permit process, and the classes are explained in more detail afterward.

Table 1.4 – Classification of possible conflicts by integrating different sources of information

Type of Conflict	Sub-Class	Examples in the building permit process
Spatial	Geometric	1) Having a 2D architectural plan and a 3D city model or vice versa Having BIM data with no information about the coordinate system
	Topologic	Intersection or overlap between two lot boundaries
Semantic	Syntactic	Apartment and Apt
	Structural or schematic	The hierarchical level of internal parts of a building in two datasets may cause conflict when it is a data value in one relational schema and a relation in another relational schema.
	Sense or meaning	1) Floor and Storey Habitable room and Bedroom
Temporal	Date	If two BIMs in the same neighbourhood at the same time request a building permit, temporal conflicts may arise.
	Duration	Some regulations depend on the existing buildings and density of a zone. For example, after reaching a specific number of buildings, the changes over the time in regulations are predictable.

- Spatial Conflicts: In the data integration process, the first important part that describes the geometric and topological inconsistencies is considered as spatial conflicts.
  - Geometric: For spatial conflicts with a geometric aspect, first, position and coordinate systems and second, shape (linked to the dimension of the point 0D, line 1D, surface 2D or polyhedron 3D primitives), size (scale factor), and orientation of the entities should be taken into account.
  - Topologic: It considers the conflicts that arise based on the interior, boundary, and exterior parts of the objects. Having polygons with non-planar surfaces or having intersection between edges or polygons are some examples of topological conflicts. It should be noted that when there is only one dataset, these conflicts could be equivalent to design conflicts.
- Semantic Conflicts: Semantic conflicts correspond to disagreement over the meaning, understanding, or intended use of the same or similar information (Fileto, 2001). Generally, these conflicts can be discussed in three levels, including:
  - Syntax level: It is related to conflicts in terms of characters (strings).

- Structure or schema level: It considers whether the same term in one dataset is located at the same level in the data model (or schema) of another dataset.
- Sense or meaning level: It consists of the conflicts that may occur between meanings of the terms.

- Temporal Conflicts: Temporal conflicts are notable in two terms of "date" and "duration". Temporal conflicts can greatly affect the building permit process. As an example of conflicts related to date, consider two high-rises in the same neighbourhood applying for the building permits. In this case, based on the date of application, the second one should not restrict rights associated with the first one. For example, the second submitted application cannot restrict solar access to the first submitted application.

1.5.2.2 Magnitude of Land-use Regulation Conflicts

As mentioned before, to support our hypothesis, we now propose a way of ranking the conflicts between the proposed planned building with physical objects and land-use regulations. We do believe that this classification will improve the decision-making process in issuing a building permit, more specifically in the integration of spatio-semantic data. Similar to clash classification in BIM (i.e., hard and soft clashes), two conflict's magnitudes for land-use regulations are proposed (i.e., hard and soft conflicts). In the proposed classification, unlike BIM clashes in which the main entities are building elements, the main entities are land-use regulations. Soft conflicts can be recognised or resolved with a limited number of data analysis by the decision-makers. While hard conflicts include situations that are more complex, for which decision-makers require a higher level of data analysis and knowledge. In the following, first, the proposed variables for evaluating the amount of data analysis are indicated and then, they are explained by three concrete examples.

1) The number of land-use regulations involved in the conflicts.
    - Soft = 1
    - Hard ≥ 2
2) The number of physical (building) objects involved in the conflicts.
    - Soft < 2
    - Hard ≥ 2
3) The level of detail[3] of the planned building (LoD "P").
    - Soft = CityGML LoD 1 (or equivalent in BIM modelling)
    - Hard = CityGML LoD 2 & LoD 3 (or equivalent in BIM modelling)
4) The level of detail of surrounding buildings (LoD "S").
    - Soft = CityGML LoD 1
    - Hard = CityGML LoD 2 & LoD 3
5) The 3D spatial configuration of the land-use regulations causing the conflict: It refers to the shapes utilised to model the land-use regulations.
    - Soft = regular solid
    - Hard = irregular 3D shapes (could be line, surface, or solid)

[3] Level of Detail (LoD) refers to the degree of detail used to model the city objects (planned building or existing buildings). For this version and as a first appraisal, we assume the 3D city model is based on CityGML but in fact, it could be any 3D modelling design.

Finally, based on the proposed variables, the number of soft and hard conflicts is counted, and the conflict belongs to the class that is outnumbered.

For instance, as is shown in Figure 1.3, the highest object of the proposed (planned) building must not exceed the maximum allowed height regulation. If it does, in this case, the conflict consists of one regulation (i.e., building height regulation) and mostly one building object (i.e., the roof of the proposed (planned) building). In addition, for identifying the conflict, since the roof shape of the proposed (planned) building is required, at least LoD 2 is needed, and adjoining existing buildings are not required. Finally, a regular solid (i.e., cuboid) can model the height regulation. Therefore, according to proposed variables, the magnitude of this conflict is "Soft" as is summarised in Table 1.5.

Table 1.5 – Classification of the magnitude of building height regulation conflict

Planned building	No. of regulations	No. of building objects	LoD "P"	LoD "S"	Spatial configuration of regulation	Class of conflict
Value	1	1	2	Not required	Regular Solid	Soft Conflict
Magnitude of conflict	Soft	Soft	Hard	-	Soft	

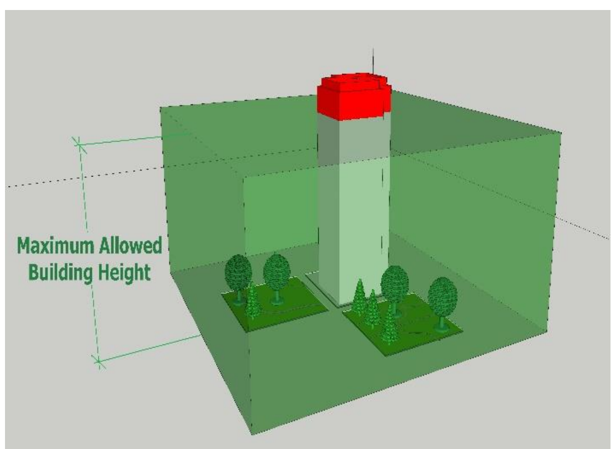


Figure 1.3 – Building height regulation conflict (in RED colour)

On the other hand, if the proposed (planned) building respects the height regulation, it may restrict the solar access of the other buildings or cause a shadow in its adjoining building as is illustrated in Figure 1.4. In this scenario, the conflict consists of two regulations (i.e., building height and overshadowing regulations) and two building objects (i.e., the roof of the planned building and private open space of existing buildings). In addition, for identifying the conflict, since the roof shape of the proposed (planned) building and the private open space of existing adjoining buildings are needed, at least LoD 2 is required for the proposed (planned) building, and for the existing buildings, LoD 3 is needed. Finally, a regular solid cannot model shadow regulation. Therefore, according to proposed variables, the magnitude of this conflict is “Hard” as is summarised in Table 1.6.

Table 1.6 – Classification of the magnitude of building height and overshadowing regulations conflict

Planned building	No. of regulations	No. of building objects	LoD “P”	LoD “S”	Spatial configuration of regulation	Class of conflict
Value	2	2	2	3	irregular shape	Hard Conflict
Magnitude of conflict	Hard	Hard	Hard	Hard	Hard	

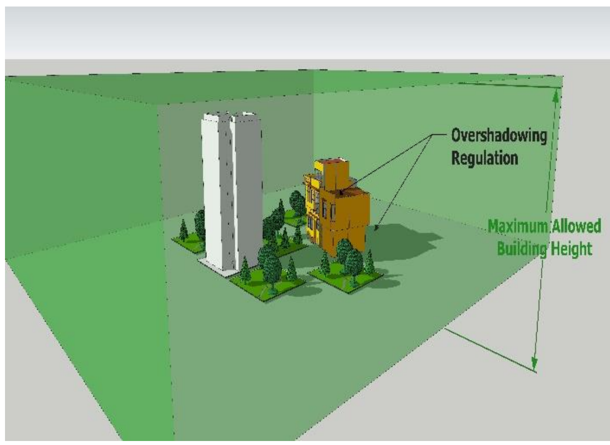


Figure 1.4 – Hard conflict between building height and overshadowing regulations (the grey is the planned building (left) and the other is the existing building (right))

As another example, as is shown in Figure 1.5, for checking overlooking regulation, the window of a habitable room of the proposed (planned) building must not provide a direct line of sight to the windows of a habitable room in existing buildings. If it does, in this case, the conflict consists of one regulation (i.e., overlooking regulation) and two building objects (i.e., the window of a habitable room in the proposed (planned) building and the window of a habitable room in the existing adjoining building). In addition, for identifying the conflict, since the windows should be modelled, the LoD 3 is needed for both proposed (planned) and existing buildings. Finally, a regular solid (i.e., triangular prism) can model the overlooking regulation. Therefore, according to proposed variables, the magnitude of this conflict is “Hard” as is summarised in Table 1.7.

Table 1.7 – Classification of the magnitude of overlooking regulation conflict

Planned building	No. of regulations	No. of building objects	LoD “P”	LoD “S”	Spatial configuration of regulation	Class of conflict
Value	1	2	3	3	regular solid	Hard Conflict
Magnitude of conflict	soft	Hard	Hard	Hard	soft	

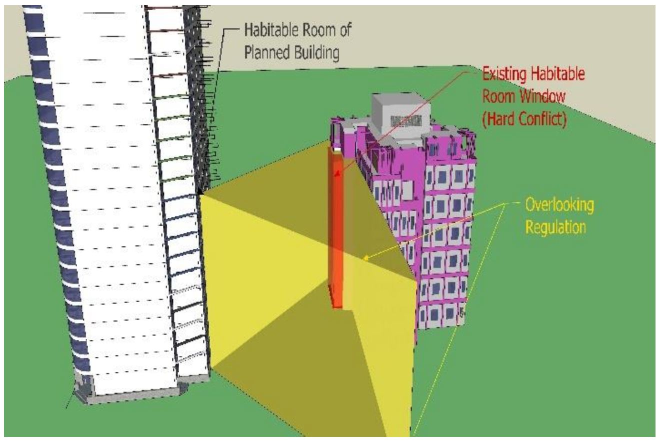


Figure 1.5 – Overlooking regulation conflict (in RED colour)

Obviously, after having ranked the conflicts between the planned building and the land-use regulations, the data processing does not stop there; we afterward have to fix the conflict. As indicated, this chapter presents the progress of an ongoing research project, and one of the next steps is exactly to provide analytical tools to meet this need.

1.6 Conclusion and Future Steps

This chapter firstly explored the land-use regulations and then, the possible conflicts that may arise in the issuance of a building permit. The inventory of land-use regulations demonstrated that many land-use regulations contain 3D components (e.g., building height, solar access, daylight, and shadowing), which make the decision-making process a challenging task with traditional 2D systems. Accordingly, after exploring land-use regulations, two classifications to identify and evaluate the conflicts are proposed from two points of view (i.e., data sources, and magnitude of conflicts). Since the building permit process is a common process in different territories, the results can be applied to other jurisdictions with some minor changes. The main value of these classifications is to extend our understanding of 3D land-use regulation and to support decision-makers in the detection of spatio-semantic conflicts between the planned building, the existing buildings, and the land-use regulations. We also believe that they will contribute to model and visualise land-use regulations as part of the 3D city modelling (CityGML and BIM). The classification system for the magnitude of the conflicts is not yet fully validated, neither confronted with a concrete decision-making process, and this is part of the upcoming work. For example, the aggregation of the variables needs to be validated with users. We are currently working on the design of a use-case to detect spatio-semantic conflicts inspired by issuing building permits and its implementation with 3D city models for the city of Melbourne.

Chapter 2 – 3D CityLuR: Modelling 3D City Land-use Regulations to Support Issuing a Planning Permit

This chapter focuses on modelling LuRs in 3D (called 3D CityLuR) automatically and combining them with other sources of information. To this purpose, this chapter identifies 3D LuRs' modelling parameters and proposed a geometric modelling approach to model each LuR based on the identified key parameters. This is the first approach extensively focusing on modelling 3D LuRs automatically as part of 3D city models. In addition, this chapter specifies BIM, 3D city models, and zoning/planning requirements to combine the modelled LuRs with other sources of information automatically. To be more specific and concretely discuss the automatic modelling of 3D LuRs, this chapter focuses on five LuRs including building height, energy efficiency protection, overshadowing open space, overlooking, and noise impacts. However, in Chapter 4, this approach will be further extended to include all the twelve 3D LuRs listed in this chapter. Finally, **this chapter does not discuss the automation of 3D LuRs' conflict detection and this aspect will be addressed in Chapter 4.**

This chapter is the original content of the following paper:

Emamgholian, S., Pouliot, J., Shojaei, D., 2021. "3D CityLuR: Modelling 3D City Land-use Regulations to Support Issuing a Planning Permit", in: *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences VIII-4/W2-2021*, pp. 113–120.

2.1 Résumé

La géorèglementation qui régit l'utilisation du territoire (nommée ici LuR pour Land-use Regulations) est plus facile à comprendre lorsqu'elle est associée à la représentation numérique du monde physique. Afin d'aider dans le processus d'émission d'un permis de construire et de progresser vers la mise en place de vérifications automatisées des permis de construire, ce chapitre étudie et propose des solutions pour modéliser en 3D les différentes géorèglementations qui peuvent s'appliquer lors de ce processus. Cette modélisation 3D des géorèglementations en vigueur, nommée ici 3D CityLuR, sert de référence pour représenter l'étendue spatiale des géorèglementations à l'échelle de la ville. 3D CityLuR tire profit de multiples approches de modélisation géométrique 3D et optimise l'automatisation du processus de construction 3D. À cette fin, selon les descriptions et les caractéristiques des géorèglementations disponibles dans des documents de planification, les paramètres clés représentant la forme des géorèglementations sont identifiés (par exemple, la distance maximale dans le surplomb ou la hauteur maximale autorisée dans les règlements sur la hauteur des bâtiments). En conséquence, pour modéliser automatiquement chaque géorèglementation, une approche de modélisation géométrique comme par exemple la représentation par frontières (B-Rep), la modélisation CSG ou encore l'extrusion, tire

profit des paramètres clés identifiés préalablement. En complément, pour combiner 3D CityLuR avec un environnement intégré BIM-GIS, la solution proposée indique le niveau d'information requis en termes de géométrie et de sémantique. Enfin, le chapitre aboutit sur un outil informatique qui démontre la faisabilité pour cinq géorèglementations comprenant la limite de construction en hauteur des bâtiments, l'exposition au soleil pour estimer l'efficacité énergétique, l'ombrage dans les espaces ouverts, les limites de vue et la réglementation des impacts sonores.

2.2 Abstract

The applications and understanding of Land-use Regulations (LuRs) are more communicable when they are linked to the digital representation of the physical world. In order to support issuing a planning permit and move towards the establishment of automated planning permit checks, this chapter investigates how LuRs related to a planning permit process can be modelled in 3D called 3D CityLuR. 3D CityLuR serves as a 3D model for representing LuRs' legal extents on a city scale. It is formed based on multiple geometric modelling approaches representing LuRs, which can provide a better cognitive understanding of LuRs and subsequently facilitate LuR automatic checks. To this purpose, according to LuRs' descriptions and characteristics explained in related planning documents, key parameters representing LuRs' extent are identified (e.g., maximum distance in overlooking or maximum allowed height in building height regulations). Accordingly, to automatically model each LuR, a geometric modelling approach (e.g., Boundary Representation (B-Rep), CSG, and extrusion) that best fits with the identified key parameters is proposed. In addition, to combine 3D CityLuR with an integrated BIM-GIS environment, the level of information need in terms of geometries and semantics is specified. Finally, the chapter results in a showcase for five LuRs including building height, energy efficiency protection, overshadowing open space, overlooking, and noise impacts regulations. The showcase is a proof of concept for determining how these LuRs can be modelled in 3D and combined with 3D city models based on the selected geometric modelling approaches, identified parameters, and level of information need.

2.3 Introduction

2.3.1 Context and Problematics

Cities are overloaded with complex multilevel developments in small proximities, causing significant challenges for managing Land-use Regulations (LuR) related to use or developments on lands (Cann, 2018; Durham Jr and Scharffs, 2019; Selmi et al., 2017). The more densified cities become, the more difficulties planning authorities have of issuing planning permits. The problem is that while LuRs in a jurisdiction, theoretically, might have vertical dimensions, their spatial instantiation and graphical representation are mainly two-dimensional (2D) (Emamgholian et al., 2020a; Olsson et al., 2018). For example, in issuing planning permits, as shown in Figure 2.1 (a), in Victoria, Australia, a proposed building façade including projections such as balconies should be set back from the side or rear boundaries not less than 1 meter, plus 0.3 meters for every meter of height over 3.6 meters up to 6.9 meters, plus 1 meter for every meter of height over 6.9 meters. Using 2D representation for verifying 3D LuRs like building setbacks, often requires significant experience and expertise to clarify the 3D dimensions of LuRs. In addition, it might cause significant shortcomings like uncertainty in decision-making especially in issuing planning permits and even cause erroneous permits (Emamgholian et al., 2020a; Van Berlo et al., 2013). In contrary, representing 3D LuRs like setbacks in 3D (Figure 2.1 (b)), decreases ambiguities regarding its extents and facilitate the conflict detection process extensively (Emamgholian et al., 2020a; Faucher and Nivet, 2000).

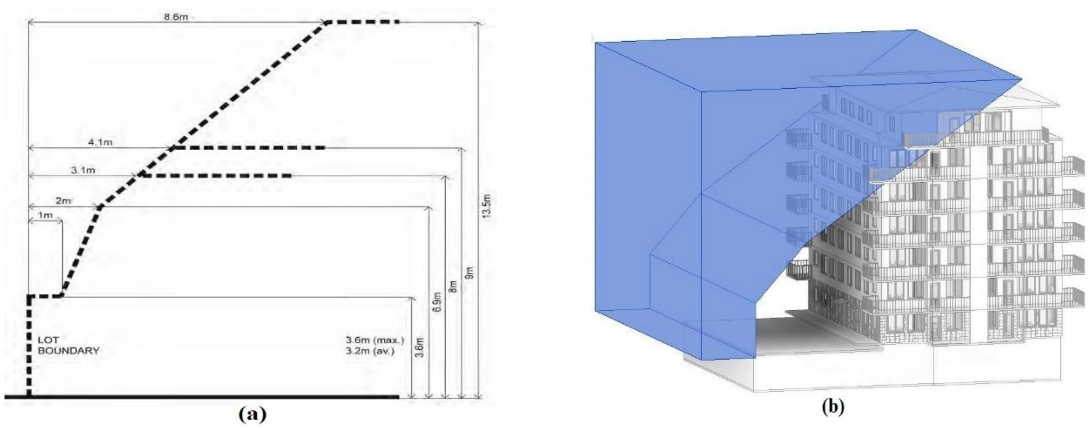


Figure 2.1 – Setback regulation, **a)** in 2D (adapted from Melbourne Planning Scheme Ordinance, p. 1244); and **b)** modelled in 3D

3D city models enable integrating various geospatial information related to issuing planning permits including proposed buildings (i.e., BIM in IFC format) and existing buildings (i.e., city data in CityGML format) into one system through 3D geo-virtual environments (Biljecki et al., 2015; Neuville et al., 2018). From the modelling point of view, the emphasis of 3D city model environments is on urban physical objects of a city such as building, relief (i.e., digital terrain model), city furniture, and transportation (Kolbe, 2009; Kolbe et al., 2020). 3D models and Building Information Modelling (BIM) can also be enriched with the representation of legal boundaries, and rights, restrictions, and responsibilities (RRR) in 3D digital cadastre (Atazadeh et al., 2017; Pouliot et al., 2018, 2016; Shojaei et al., 2018; Stoter et al., 2016).

The multi-dimensional nature of 3D city models with the capability of 3D analyses can also provide the ability to consider this environment for the representation of LuR extents in both statutory and strategic planning phases. In addition, intended users (e.g., lawyers, urban planners, urban specialists, and land surveyors), as well as the responsible authority for issuing planning permits (e.g., council), are more familiar with this environment rather than BIM which is more familiar for architects and building designers (Olsson et al., 2018).

2.3.2 Objectives

This study is part of a research project started in 2019 in collaboration between Université Laval (Centre for Research in Geospatial Data and Intelligence) and the University of Melbourne (Centre for SDIs and Land Administration) to address the problem of detecting potential conflicts among 3D LuRs and physical objects. In the first phase of this project, the magnitude of potential LuR conflicts was classified into two classes as soft and hard conflicts. The 3D spatial configuration of LuRs referring to the shapes utilised to model LuRs was one of the prominent variables to classify the potential conflicts (see Emamgholian et al. (2020a)). Accordingly, as the second phase of this project, this chapter aims to investigate how 3D LuRs related to the planning permit process can be modelled in 3D and then combined with an integrated BIM-GIS environment to support the conflict detection and issuing planning permit processes considerably.

To this purpose, for the modelling part, first, the key parameters of 3D LuRs are identified mainly from legal planning documents and then, a geometric modelling approach (e.g., B-Rep, CSG, extrusion) that best fits with the key parameters is proposed to model LuRs in 3D. The results of this stage called 3D CityLuR, which is a 3D model for representing LuRs on a city scale. It is formed based on multiple geometric modelling approaches representing LuRs, which can be used to validate proposed buildings against LuRs automatically in a later stage. For the combination part, the level of information need in terms of geometries and semantics are proposed with a focus on combining 3D CityLuR with an integrated BIM-GIS environment. The results create a linkage between LuRs and physical objects to support having a digital planning permit.

With this in mind, the next section provides a comprehensive review of the concepts underlying this study (e.g., geometric modelling approaches and level of information need). Section 2.5 presents the proposed approach, which is followed by implementing a 3D city model integrated with 3D CityLuR in Section 2.6 to showcase the feasibility of the proposed approach. The showcase realised as a proof of concept for determining how the LuRs related to the planning permit process can be modelled in 3D and combined with 3D city models. The final section concludes the chapter with the main findings and directions for future research.

2.4 Review of Concepts Underlying This Study

2.4.1 Planning Permits in the City of Melbourne

Since the LuRs foundation for managing land “use” and “development” varies between jurisdictions (Emamgholian et al., 2020a; Noardo et al., 2020a), this chapter focuses on a specific jurisdiction i.e., the state of Victoria, Australia. However, the proposed approach tries to be generic, and it can be applied to other jurisdictions if differences in terms of LuRs’ descriptions are considered. According to Victoria’s planning system[4], a planning permit is "*a legal document that allows a certain use or development to proceed on a specified parcel of land*". Depending on the densification level of developments, city councils or the planning minister are the responsible authorities who issue planning permits mainly based on the planning scheme and its requirements.

The planning scheme is a legal document in which objectives, policies, and provisions related to the use, development, and protection of lands are indicated. It has several components such as zones, overlays, State Planning Policy Framework (SPPF), Local Planning Policy Framework (LPPF), particular provisions, general provisions, and schedules, and generally aims to regulate the "use" and "development" of land by planning regulations to make sure policies are met. It should be noted that based on Victorian definitions, a planning permit should not be confused with a "building permit" that will be issued based on the building codes considering the construction or alteration aspects of a building or development. This chapter only considers LuRs related to issuing planning permits for building one, two or more dwellings on a lot, residential buildings, apartments with less than five storeys, and apartments containing five or more storeys.

2.4.2 Geometric Modelling Approaches

This section outlines the geometric modelling approaches that are the main focus of this chapter. Generally, geometric modelling approaches can be categorised into two main groups including space-oriented and object-oriented for which there are different modelling approaches (Pouliot et al., 2006). In the space-oriented group (also called spatial occupancy enumeration) (e.g., voxel and octree), unlike the object-oriented group, usually, there are no holes left and everything in space is occupied. Implicit modelling resulting from a continuous mathematical representation by establishing a mathematical formula (Szeliski, 2010), can be linked with this group as well. However, explicit and object-oriented modelling that represents 3D objects by their constituent geometric elements with a fixed number of primitives (i.e., point, line, polygon, solid), are the focus of this study.

With this in mind, the modelling approaches in the object-oriented group (as the scope of this chapter) mostly include wireframe (Ying et al., 2020), primitive instancing (De La Losa, 2000), Boundary representation (B-Rep) (Zlatanova, 2016), solid modelling (Knoth et al., 2020), Constructive Solid Geometry (CSG) (Jarroush and Even-Tzur, 2004; Knoth et al., 2020; Ying et al., 2020), sweeping (Knoth et al., 2020; Ying et al., 2020), and extrusion (Emamgholian et al., 2020b, 2017). Knoth et al. (2020), Ying et al. (2020), Ohori (2016), and Zlatanova (2016) have extensively reviewed different geometric modelling approaches such as B-rep, CSG, extrusion, and sweeping.

[4] https://www.planning.vic.gov.au/guide-home/using-victorias-planning-system

2.4.3 Level of Information Need

BIM and CityGML data use a multi-incremental Level of Development (LODev)[5] and Level of Detail (LoD) number scale, respectively, to show the complexity of 3D models in different aspects such as geometries and semantics (i.e., 100 to 500 LODev in BIM, and 0 to 4 LoDs in CityGML v2) (Kolbe et al., 2005; Latiffi et al., 2015). Based on different applications, specific LODev and LoDs might be required to achieve a fit-for-purpose solution. For example, in issuing planning permits, for modelling LuRs in 3D and combining them with 3D city models, each LuR needs a specific LODev in the BIM design of a proposed building and a specific LoD in CityGML data of existing buildings (Emamgholian et al., 2020a). However, often by using the LODev/LoD concepts solely, planning authorities still need to check 3D models as well as planning maps and documents to make sure all the required information is included.

Information requirements as “level of information need” and its concept and principles are discussed in EN ISO 19650 series with a focus on BIM. In addition, BS EN 17412-1 proposes a level of information need framework to define quality, quantity, and granularity of information requirements again in BIM. It discusses that based on different purposes, level of information need can vary in terms of geometrical information, alphanumeric information, and documentation.

In this chapter, level of information need refers to both IFC/CityGML requirements and required planning information (e.g., zoning base map) to model LuRs automatically in the context of issuing planning permits. Taking overlooking regulation as an example, the window of a habitable room of a proposed building must not provide a direct line of sight to the windows of habitable rooms in existing buildings. As indicated in this example, although using LODev/LoD concepts might assure the existence or nonexistence of a window, it does not guarantee that the city data and BIM design distinguish habitable room windows from other windows. This point refers to the required information as level of information need.

2.5 Methodology

To achieve the objectives (section 2.3.2), an approach that mainly includes two stages is proposed. The two stages are: **1)** modelling 3D LuRs (called 3D CityLuR) by defining their key parameters and selecting a geometric modelling approach for each LuR, and **2)** combining 3D CityLuR with 3D city models by determining the level of information need with a focus on geometric and semantic aspects of required information in 3D models and planning information as well as its linkage with LODevs/LoDs for proposed/existing buildings and city furniture. Although these two stages can be done simultaneously, in this chapter, to have a better impression, they are explained separately.

[5] Acronym “LoDev” is used for Level of Development in BIMs to distinguish it from Level of Detail (LoD) in CityGML.

2.5.1 Modelling LuRs in 3D (3D CityLuR)

Based on an updated version of the inventory proposed by Emamgholian et al. (2020a) in Victorian jurisdiction subject to the planning approval, Table 2.1 shows thirteen identified 3D LuRs categorised into five groups. In this chapter, five LuRs are selected (coloured in orange) to be modelled and further discussed. The selection is in a way that covers the applicability of different geometric modelling approaches including extrusion, B-rep, CSG, and sweeping for representing 3D CityLuR as a 3D model using multiple geometric modelling approaches.

Table 2.1 – Inventory of 3D LuRs and their categories (in orange, selected LuRs for tests)

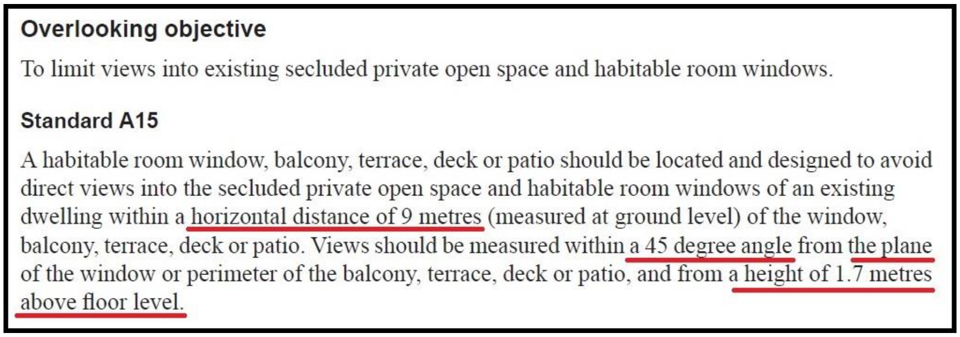
Class	LuRs
Zoning and dimensioning	Building Height
	Side and Rear Setbacks
	Street Setbacks (Side and Front)
	North-facing Windows
Overshadowing	Energy Efficiency Protection
	Overshadowing Open Space
Daylight and Solar Access	Solar Access to Open Space
	Daylight to Existing Windows
	Daylight to New Windows
Viewshed	Overlooking
	Internal Views
Environmental	Noise Impacts
	Flooding

2.5.1.1 LuRs' Key Parameters

Parameters in this chapter are any characteristics (e.g., dimensions) that are extracted from related documentations, plans, etc. as input information to enable the geometric modelling of LuRs automatically. Therefore, for defining 3D CityLuR's key parameters, after exploring each LuR extensively, based on their descriptions and characteristics, the key parameters were identified. Key parameters are required to automatically instantiate each LuR, and without them, the modelling phase fails. Since the modelling approach would be selected according to these parameters, they are called "key" parameters in this study. It should be noted that unselected LuRs in Table 2.1 can be modelled similarly with differences in their key parameters. It should also be noted that although converting the LuRs' description to a machine-readable format is not the focus of this study, it can be applied in this stage to extract some of the key parameters automatically. The identified key parameters for the selected LuRs are discussed below.

Taking overlooking regulation as the first example, based on its description shown in Figure 2.2, four key parameters are identified including:

1) **HDo:** horizontal distance limit (i.e., 9 meters);
2) **Wo:** width of habitable room windows, balconies, terraces, decks, or patios of the proposed building;
3) **RZo:** rotation along the Z-axis; and
4) **Ho:** height of the window's floor level.



Overlooking objective

To limit views into existing secluded private open space and habitable room windows.

Standard A15

A habitable room window, balcony, terrace, deck or patio should be located and designed to avoid direct views into the secluded private open space and habitable room windows of an existing dwelling within a horizontal distance of 9 metres (measured at ground level) of the window, balcony, terrace, deck or patio. Views should be measured within a 45 degree angle from the plane of the window or perimeter of the balcony, terrace, deck or patio, and from a height of 1.7 metres above floor level.

Figure 2.2 – Overlooking description (adapted from Melbourne Planning Scheme Ordinance, clause 54.04-6)

By considering building height regulation, the vertical distance between ground level and the highest point in the proposed building should not exceed the maximum allowed height specified in a zone, schedule to the zone, or an overlay that applies to the land. Accordingly, two key parameters are identified for modelling building height regulation including:

1) **Hb (i):** height limits in each precinct based on height regulation; and
2) **Dhb (ij):** planning zones' dimensions on the terrain.

Energy efficiency protection regulation considers the effect of overshadowing on an existing rooftop solar energy system on an adjoining lot. For overshadowing open space regulation, the overshadowing on existing secluded private open space will be checked. For both LuRs, the proposed building's shadow volume is required. For modelling shadow in 3D, two parameters are identified including:

1) **Psh (i):** corner points of the proposed building's shadow on the terrain (or points of proposed building's shadow with a pre-defined threshold in more complex shadows); and
2) **Pshb (i):** related points of the proposed building façade causing a shadow on the terrain.

By considering noise impacts regulation, as the last LuR, residential buildings and dwellings near busy roads, railway lines, or industries should be designed in a way that limits noise levels in habitable rooms. The 3D impacts of noise depend on the noise sources (i.e., road, railway line, or industry) and their specified distances from the nearest trafficable lane/track in the planning scheme. Accordingly, two parameters are required to model this LuR including:

1) **Dn (i):** Affected distance; and
2) **Ln (i):** Length (of roads or railway lines).

2.5.1.2 LuRs' Geometric Modelling

Based on the identified key parameters of 3D LuRs, a geometric modelling approach that best fits with the identified parameters is proposed for each LuR. It should be noted that although modelling parameters may change in a specific case based on the LuR description in that area (e.g., setback limits are not the same for all precincts), the modelling approach and the procedure will remain the same. In addition, based on the scope of this chapter, in this stage, we are not aiming to compare different modelling approaches, but to select one for each LuR based on their identified key parameters. That is why 3D CityLuR utilise multiple geometric modelling approaches to model 3D LuRs.

Taking overlooking regulation as an example, by considering its identified parameters (see Figure 2.2), it can be geometrically modelled by using the CSG approach in which a cylinder and a cuboid are combined by using intersect operator (Figure 2.3). Table 2.2 shows the dimensions of cylinder (r, h) and cube (l=w, h) based on its identified parameters (HDo, Wo, Ho).

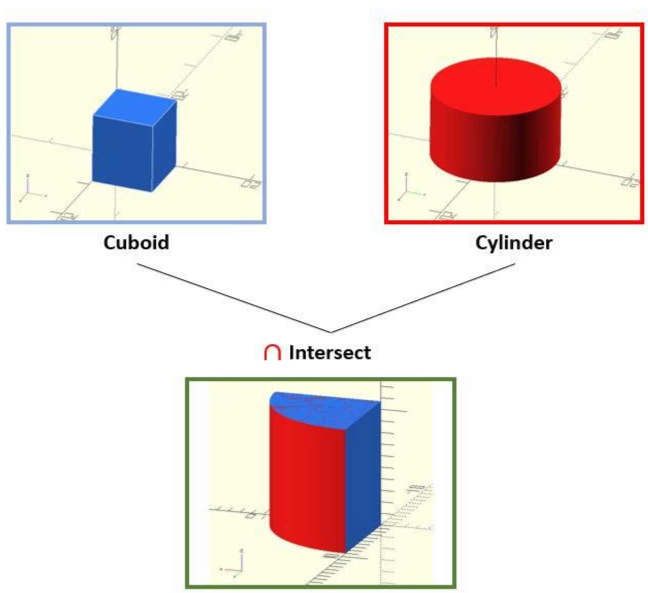
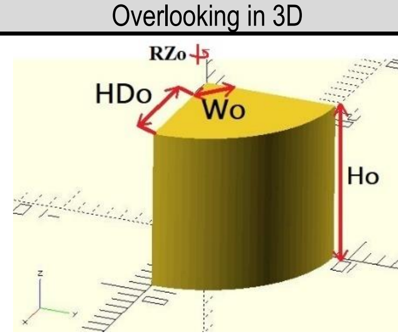


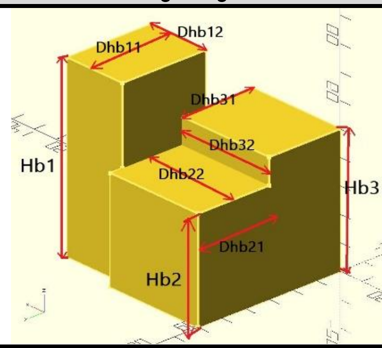
Figure 2.3 – Modelling overlooking regulation using CSG

Table 2.2 – Modelling overlooking LuR based on its identified parameters

Modelling Approach	Overlooking in 3D
CSG: Cylinder ∩ Cube Cylinder (r, h): r = HDo + (√2*Wo/2) h = Ho Cube (l = w, h): l = HDo + (√2*Wo/2) h = Ho	

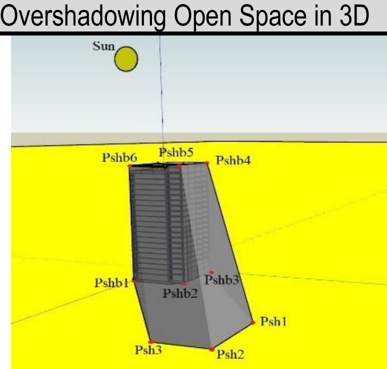
By considering building height regulation and its identified parameters, it can be geometrically modelled by extruding 2D polygons of zoning base map using Hb values in each zone. Table 2.3 shows building height regulation in 3D with its identified parameters.

Table 2.3 – Modelling building height LuR based on its identified parameters

Modelling Approach	Building Height in 3D
Extrusion: Extruding 2D polygons by using Hb values	

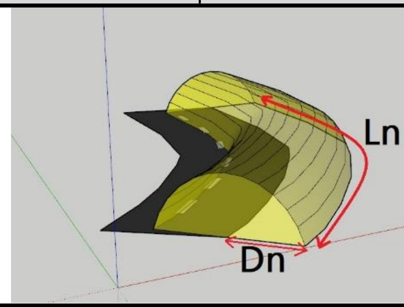
For energy efficiency protection and overshadowing open space regulations, since their 3D extents vary based on the geometric shape and size of the proposed building, we propose to model it by using the B-Rep approach based on the identified parameters (i.e., Psh (i) and Pshb (i)). Table 2.4 shows energy efficiency protection and overshadowing open space regulations in 3D with its identified parameters. In section 2.6, the extraction of Pshb points using a reverse engineering method based on the notion of sun rays are discussed.

Table 2.4 – Modelling energy efficiency protection and overshadowing open space LuRs based on their identified parameters

Modelling Approach	Energy Efficiency Protection and Overshadowing Open Space in 3D
B-Rep: By using the notion of sun rays for Psh (i) points, Pshb (i) points can be extracted	

As the last LuR, for modelling noise impacts of roads and railway lines, a semicircle can be swept along the length of the paths or tracks. Table 2.5 shows noise impact regulation (e.g., for roads) in 3D with its identified parameters.

Table 2.5 – Modelling noise impacts LuR based on its identified parameters

Modelling Approach	Noise impacts in 3D
Sweeping: Sweeping a semicircle along an irregular path/track	

2.5.2 Combining 3D CityLuR with 3D City Models

After specifying modelling parameters of each LuR and selecting a suitable geometric modelling approach, 3D CityLuR should be combined with the 3D city model. Because of diversity of LuRs' characteristics and parameters and since each LuR might be geometrically modelled differently, 3D CityLuR is formed outside of 3D city models. Hence, 3D CityLuR also can be combined with any kind of 3D models. However, since CityGML and BIM are major trends in 3D modelling area, in this chapter, a specific effort has been made to address the combination of 3D CityLuR with them. Therefore, in this chapter, it is assumed that the 3D city model is an integrated BIM-GIS environment consisting of existing buildings in CityGML format and a proposed building model as BIM in IFC format.

LODev in BIMs and LoD in 3D city models can vary based on different applications. In planning applications especially for issuing planning permits, they can significantly affect the process of modelling LuRs and combining them with 3D city models. However, since information requirements might not necessarily be linked with the LODev/LoDs in different applications and use-cases, specifying the required LODev/LoDs for 3D models cannot fully guarantee that the 3D CityLuR can be combined with 3D city models. For instance, planning information like zoning base map or some additional information might be required that is related to neither BIM LODev nor CityGML LoDs. Taking overlooking LuR as an example, in this case, access to specific geometries and semantics like a window, balcony, terrace, deck, and patio are required. This means an LODev 300 for BIM design of a proposed building is required. In addition, knowing some attributes like the function of windows (e.g., habitable room windows) is also required for modelling this LuR. The latter refers to the level of information need. Therefore, considering the level of information need and minimum required LODev/LoDs together is necessary to combine 3D CityLuR with the 3D city model successfully. In that regard, this stage defines the level of information need with a focus on required planning information and BIM/CityGML requirements as well as required IFC LODev/CityGML LoDs for the selected LuRs in order to combine 3D CityLuR with 3D city models ideally. This stage presents desired circumstances that assure the combination stage can be done automatically.

Table 2.6 shows the proposed level of information need and required LODev/LoDs for the selected LuRs that previously discussed. The level of information need considers both geometries and semantics (i.e., class of object and attributes) for modelling LuRs and combining them with the proposed building and existing buildings. It should be noted that in this chapter temporal aspects of LuRs are not discussed thoroughly, and they are considered as part of attributes whenever is required (e.g., in overshadowing open space). It should also be noted that this stage does not discuss the conflict detection stage in which the information requirements differ. The next section presents a showcase as a proof of concept to demonstrate the feasibility of the proposed stages to model 3D LuRs and combine them with 3D city models by using CesiumJS 3D tiles.

Table 2.6 – Required planning information and LODev/LoDs for combining 3D CityLuR with the 3D city model

	Required Information as Level of Information Need			Required LODev/LoDs	
		Semantic			
LuR	Geometry	Class of Object	Attribute	IFC LODev	CityGML LoD
Building Height Regulation	Zoning base map (polygon) geometries	-	• Zones' category (road, port, capital city, industrial, etc.) • Height limit	Not required	Not required
Energy efficiency protection	2D shadow (polygon) geometries of proposed building on the terrain	-	• Belongs to (proposed building/ existing buildings) • Dates and times (specified dates and times in the planning scheme for checking overshadowing)	300	Not required
Overshadowing Open Space		Shadow			
Overlooking	Window geometries of proposed buildings	Window	• Function (habitable room, etc.) • Floor Height	300	Not required
	Balcony/ Terrace/ Patio geometries of proposed buildings	Balcony/ Terrace/ Patio	• Floor Height		
Noise impacts	Street, railway line, and industry geometries in zoning base map surrounding proposed buildings	-	• Name of road/ railway line/ industry • Category of road/ railway line	Not required	Not required[6]

[6] LoD 2 is required whenever there is no street, railway line, and industry geometries in zoning base map surrounding proposed buildings

2.6 Showcase

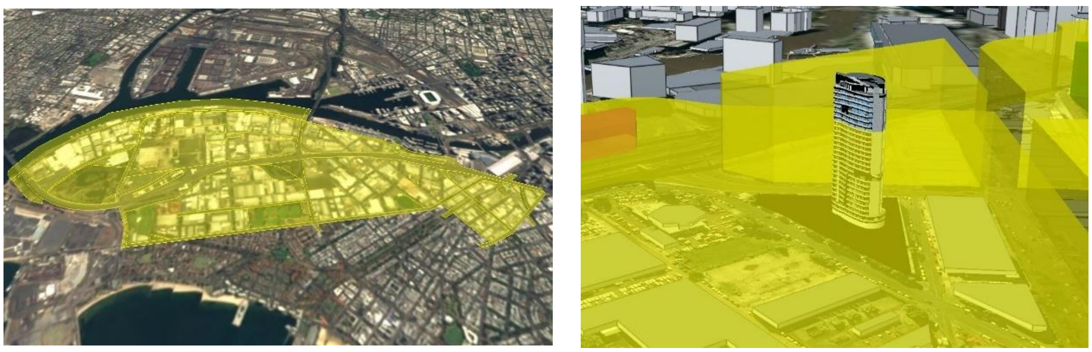
The Showcase aims to demonstrate the feasibility of the two-stage proposed approach for modelling LuRs in 3D and combining them with the 3D city model. In this showcase, planning authorities are the lead beneficiary of 3D CityLuR. This showcase, as a proof of concept, consists of programming inside a web-based application (i.e., Cesium) using JavaScript.

In this stage, a sample high-rise building in IFC format (as the proposed building) converted to 3D tile format and imported to the Cesium ion. It should be noted that the BIM-GIS integration challenges (e.g., georeferencing BIM design, and converting IFC to 3D tile) are not addressed here, and we assume that this part is currently done by using software like FME to have a combined format as 3D tile which is suitable for visualising and managing large datasets. The following notes demonstrate the results for the selected 3D LuRs including overlooking, building height, energy efficiency protection, overshadowing open space, and noise impacts regulations, respectively.

- **Overlooking:** For this LuR, the showcase only considers a habitable room of the proposed building. However, for other building elements (e.g., balcony and terrace) the process is quite similar. According to Table 2.2, overlooking regulation was modelled using CSG by combining a cube and a cylinder using intersection operator (this part is done in OpenJSCAD). Moreover, the cylinder's dimensions (r, h) as well as the cube's dimensions (l=w, h) were calculated by having access to the window's width and floor height. Finally, according to Table 2.6, it was combined with the 3D city model by having access to the window of habitable room in the proposed building (Figure 2.4). Similarly, this process can be applied to all the habitable rooms windows.

Figure 2.4 – Overlooking regulation in 3D using CSG

- **Building height:** For modelling this LuR, 2D planning scheme zones, as zoning base map that is managed by the Department of Environment, Land, Water & Planning (DELWP[7]) was used for Fishermans Bend precinct (this zoning map is required according to the proposed level of information need in Table 2.6). Based on zones' category (e.g., Capital City Zone) and height limits in each zone that have been added to the model as attributes, the Shapefile zoning map converted to GeoJSON and imported to Cesium ion (Figure 2.5 (a)). As specified in Table 2.3, an extrusion approach based on the height limit attributes was used to model this LuR in 3D as shown Figure 2.5 (b).



(a) **(b)**

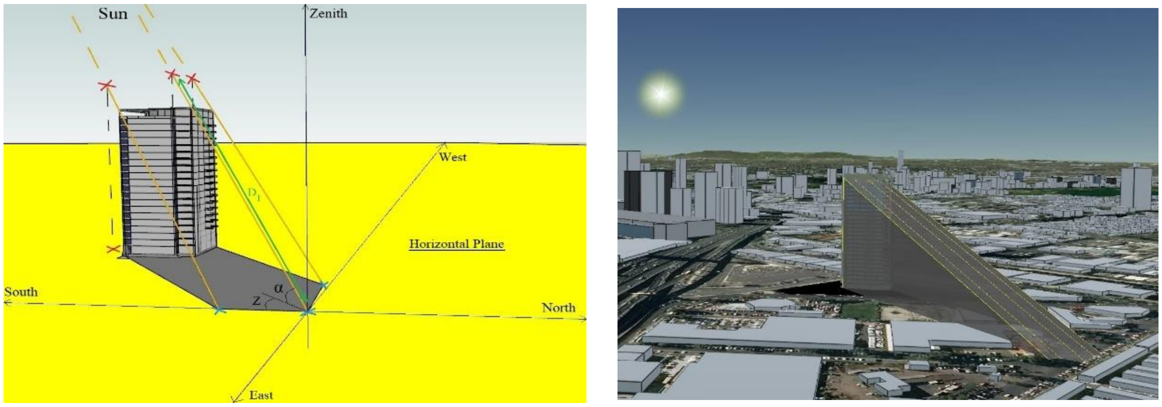
Figure 2.5 – **a)** Part of zoning map in Fishermans Bend precinct; **b)** Building height regulation in 3D using extrusion

- **Energy efficiency protection and overshadowing open space:** Although the application of energy efficiency protection and overshadowing open space regulations is different, their modelling process is quite similar. Currently, available software and APIs mostly can model 2D shadows. By having access to the coordinates of corner points of the proposed building's shadow on the terrain and considering the sun's position (altitude: α; azimuth: z) at the specified dates and times, these LuRs can be modelled in 3D using a reverse engineering method based on the notion of sun rays.

  In this case, shadow points on the terrain serve as observer points that should be tracked along the sun's position to identify the top points. We used the position of the proposed building (e.g., the centre) for determining the oblique Distances (Di) for extracting the top shadow points of the proposed building. Figure 2.6 (a) shows how from 2D shadow points, Di, α, and z, other points' position can be extracted (i.e., red multiplication signs). After extracting top points for a specific time (e.g., 22nd of September at 12:00 p.m. as one of the specified times for checking shadows in the planning scheme), by all the points including points of 2D shadow on the terrain and top points, the shadow volume can be modelled in 3D using B-Rep (Figure 2.6 (b)).

  Since in a later stage, we are aiming to detect potential conflicts between modelled overshadowing regulation with adjoining buildings, its overlap with the proposed building does not affect issuing planning permits. In addition, when the proposed building shape gets more complex, this method still can be applied and saves time and efforts. However, for having an accurate shadow in 3D, extracting corresponding building geometries and shadow points is necessary.

[7] https://www.delwp.vic.gov.au/



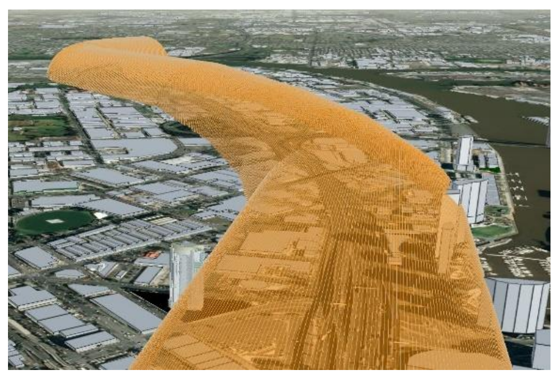
(a) **(b)**

Figure 2.6 – **a)** Extracted points (red multiplication signs) based on α (i), z (i), and D (i) for the 2D shadow points; **b)** Energy efficiency protection and overshadowing open space regulations in 3D using B-Rep

- **Noise impacts:** To model noise impacts in 3D, a road zone in category 1 in Fishermans Bend was selected. According to Melbourne's planning scheme ordinance, the proposed building's construction materials need to be further checked if the proposed building is at less than 300 meters distance from the nearest lane of a freeway (Figure 2.7 (a)). By considering this distance as Dn parameter (according to Table 2.5), noise impacts regulation can be modelled and combined with the 3D city model by sweeping a semicircle (r: 300) along the road's path (Figure 2.7 (b)). It should be noted for simplicity, noise impacts regulation is illustrated for a part of a freeway. However, the process is the same for other linear noise sources except for an industry for which a hemisphere can be used for modelling noise impacts regulation.

Noise source	Noise influence area
Zone interface	
Industry	300 metres from the Industrial 1, 2 and 3 zone boundary
Roads	
Freeways, tollways and other roads carrying 40,000 Annual Average Daily Traffic Volume	300 metres from the nearest trafficable lane
Railways	
Railway servicing passengers in Victoria	80 metres from the centre of the nearest track
Railway servicing freight outside Metropolitan Melbourne	80 metres from the centre of the nearest track
Railway servicing freight in Metropolitan Melbourne	135 metres from the centre of the nearest track

Note: The noise influence area should be measured from the closest part of the building to the noise source.



(a) **(b)**

Figure 2.7 – **a)** Noise influence area for different noise sources (adapted from Melbourne Planning Scheme Ordinance, p. 1281); **b)** noise impact regulation in 3D using sweeping

2.7 Conclusion and Future Steps

This chapter proposed a two-stage approach to model 3D LuRs extents as 3D CityLuR and combine it with 3D city models automatically to support the decision-making process in issuing planning permits. To our knowledge, the proposed approach is the first one extensively focusing on modelling LuRs in this field and as part of 3D city models.

In the first stage, key modelling parameters were extracted from legal notes of LuRs and accordingly, a geometric modelling approach that best fits with those parameters was proposed. As the main result of this stage, 3D CityLuR representing LuRs extents was formed automatically based on multiple proposed geometric modelling approaches. In the second stage, to combine 3D CityLuR with 3D city models automatically, the level of information need covering both required planning information and BIM/CityGML requirements in terms of geometries and semantics, as well as the required LODev/LoDs in proposed/existing buildings, were proposed. Without this stage, 3D CityLuR cannot be combined with 3D city models automatically. In addition, as an outcome, this stage makes the decision-making process shorter since planning authorities do not need to check 3D models as well as planning maps and documents to make sure all the required information is included. Moreover, it is a basis for a later stage which is to detect potential conflicts among 3D CityLuR and 3D city models to have a digital planning permit. After presenting the proposed approach, the chapter resulted in a showcase for five LuRs including building height, energy efficiency protection, overshadowing open space, overlooking, and noise impacts. Although the planning permit process may vary in different jurisdictions, there are many similarities in general rules defining LuRs. Therefore, the proposed approach can be applied to others if differences in terms of LuRs' descriptions are considered. In addition, if there is no distinction between planning and building permit processes, it can still be applied to building regulations related to planning purposes.

As the commercialisation of digital planning/building permits increases in importance, integrating the concept of LuRs and automating their 3D representation gain more value in markets in the near future. We believe that it will also contribute to automatically detect potential conflicts between the proposed building, the existing buildings, and the LuRs in a later stage.

Chapter 3 – 3D Zoning: A Missing Piece to Link Planning Regulations with 3D Cadastre

In this chapter, we are interested in opening a discussion regarding the advantages of enriching 3D zoning with the spatial representation of 3D LuRs and its link with 3D cadastre to find better compliance between land use, urban planning, and citizen welfare. With the knowledge gained from the previous chapters, this chapter first specifies 3D LuRs that do not need any physical objects like building elements to be modelled in 3D. Then, this chapter proposes to enrich 3D zoning with the 3D representation of these specific LuRs as the missing piece to link planning with 3D cadastre which can be highlighted as the main contribution of this chapter.

This chapter is the original content of the following paper:

Emamgholian, S., Pouliot, J., Shojaei, D., 2021. "3D Zoning: A Missing Piece to Link Planning Regulations with 3D Cadastre", in: *Proceedings of the 7th International FIG 3D Cadastre Workshop*, New York, NY, USA. pp. 11–13.

3.1 Résumé

Lorsque de nouveaux développements sont proposés dans une ville, on doit vérifier si ceux-ci respectent la géorèglementation en vigueur (comme par exemples les limites de construction, les zones inondables, etc). L'un des officiers publics appelés à effectuer ce genre de vérification est l'arpenteur-géomètre, qui en particulier lors de l'établissement des limites d'une propriété ou encore lors d'un certificat de location doit s'assurer de présenter et expliquer adéquatement les géorèglementations touchant cette propriété. Les éléments verticaux de la propriété comme par exemple, la hauteur du bâtiment, l'élévation du terrain, font partie de cette démarche de validation avec les lois et règlements en vigueur. Il nous appert que la représentation en 3D, que ce soit au niveau des limites cadastrales ou encore pour la géorèglementation, est un passage obligé pour assurer une saine gestion du territoire et mieux protéger les droits des citoyens. Par exemple, pouvoir conjuguer un cadastre 3D avec un zonage en 3D, nous semble pertinent et possiblement essentiel. Ce chapitre vise à offrir une discussion sur les avantages d'utiliser un cadastre 3D multifonctionnel qui inclurait la représentation des géorèglementations en vigueur. À cette fin, trois groupes de géorèglementations sont proposés (c'est-à-dire modélisation unique du géorèglement, modélisation intégrée avec le modèle de ville en 3D et modélisation par zonage 3D). Pour appuyer notre discussion sur la modélisation des géorèglementations dans un cadastre multifonctionnel, le chapitre présente cinq géorèglementations de planification qu'on peut inclure dans un zonage 3D, notamment les limites de hauteur, les impacts sonores, les marges de recul latérales et arrière, les marges de recul des rues (latérales et avant) et les limites d'inondation. Un bâtiment situé dans la ville de

Melbourne où l'application de la géorèglementation est sous le contrôle de l'État de Victoria, Australie a été choisi comme étude de cas pour illustrer certains aspects de la discussion.

3.2 Abstract

Interpreting planning regulations could be a challenging task for land surveyors when defining new ownership boundaries and for responsible authorities (e.g., city council) when assessing proposed developments. They need to be aware of the impacts of planning regulations on land parcels and vice versa since these regulations contain legally binding rules for all parties including government and citizens. There is a strong link between planning and cadastral regulations. For example, 3D zoning, with the capability of representing planning regulations in 3D, has a great potential to enable representing restricted and usable spaces for 3D cadastral purposes in a more visual way. This chapter aims to offer a discussion about the advantages of enriching 3D zoning with the spatial representation of planning regulations in order to be integrated into a larger land-use information system called multipurpose cadastre to find better compliance between land use, urban planning, and citizen welfare. To this purpose, three groups of planning regulations (i.e., proposed design needed, 3D city model needed, and 3D zoning groups) are proposed in which 3D zoning group seems to be the most valuable one to achieve the overall objective. To support our discussion regarding mapping planning regulations for cadastral purposes, the chapter results in a showcase for five planning regulations in the 3D zoning group including height limits, noise impacts, side and rear setbacks, street setbacks (side and front), and flooding limits. The City of Melbourne (where planning activities are under the control of authorities in the state of Victoria, Australia) was selected as a case study to illustrate some aspects of the discussion.

3.3 Introduction

3.3.1 Context and Problematics

In urban planning, zoning is a regulatory mechanism that categorizes or divides land parcels into areas called zones (Selmi et al., 2017). In each zone, a set of regulations controls uses and developments on land with the purpose of mediating between social space and physical space for orderly urban growth and development (Salsich and Tryniecki, 1998; Selmi et al., 2017). Currently, most cities are using 2D zoning maps with a color-coded system in which clicking on a city zone will bring up general information about that zone. Based on this information, related planning regulations should be found in primary and secondary sources such as regulatory documents (Plazza et al., 2019). This method might cause significant shortcomings like in understanding restricted and usable spaces especially when most of the planning regulations contain 3D components (e.g., building height and setback limits). Usable spaces in this chapter refer to spaces that are not restricted by planning regulations and can be used for defining new ownership boundaries.

Beyond visualisation capacity, 3D zoning will gain value if they are integrated with the process of checking the compliance of land developments with planning and zoning regulations (Mayer and Somerville, 2000; Noardo et al., 2020a; Valencia et al., 2015; Van Berlo et al., 2013). In addition to preventing new uses and developments from interfering with existing uses and developments, it would be beneficial to use 3D zoning to control strategic planning rules and policies related to urban renewal and developments (Bracken, 2014; Brown et al., 2018; Cann, 2018; Durham Jr and Scharffs, 2019; Kochan, 2014). For instance, one of the difficult tasks for architects and land surveyors is to understand and identify regulations limits in city zones before designing and subdividing a multi-owned development when defining new ownership boundaries (Emamgholian et al., 2020a; Grimmer, 2007).

Due to the complexity and multi-dimensionality of zoning and planning regulations, identifying potential conflicts during designing and subdividing multi-owned buildings is not an easy task and requires lots of expertise, specialised knowledge, and analytical skills especially when 3D components are involved (Benner et al., 2010; Emamgholian et al., 2020a; Noardo et al., 2020c; Olsson et al., 2018; Plazza et al., 2019). In these situations, regulations limits must be accurately identified and considered when defining new ownership boundaries in cadastral plans. Enriching 3D zoning in which planning regulations are instantiated can significantly make the decision-making process faster and more communicable and improve the cognitive understanding of regulations limits for land administration and planning authorities (e.g., urban planners, architects, and land surveyors) (Emamgholian et al., 2021a; Faucher and Nivet, 2000; Schaller et al., 2015; Schueren et al., 2016). Therefore, the benefits of enriching 3D zoning with the 3D representation of planning regulations can facilitate identification, validation, and registration of Rights, Responsibilities, and Restrictions (RRRs) for proposed developments in each precinct.

3.3.2 Objectives

This study offers a discussion mainly based on the findings in a research project started in 2019 in collaboration between Université Laval (Centre for Research in Geospatial Data and Intelligence) and the University of Melbourne (Centre for SDIs and Land Administration) focusing on modeling 3D land-use regulations and detecting potential conflicts among regulations and physical objects. As the first phase of the project, Emamgholian et al. (2020a) proposed five variables to classify the potential conflicts as soft and hard conflicts. The variables were: number of 1) regulations and 2) physical objects involved in the conflicts, level of detail of the 3) proposed building and 4) surrounding buildings, and 5) spatial 3D spatial configuration of regulations. As the second phase of the project, Emamgholian et al. (2021a) proposed a novel approach for modeling land-use regulations geometrically to validate proposed buildings against regulations in a later stage. From the modeling perspective, the key parameters, and a geometric modeling approach (e.g., extrusion, B-Rep, CSG, sweeping) that best fits with the identified parameters were proposed. Moreover, a level of information need for combining modelled regulations with 3D city models focusing on required planning information as well as physical objects was discussed considerably.

Based on our knowledge and experience, this chapter aims to open a discussion about the advantages of enriching 3D zoning with a spatial representation of planning regulations that can be integrated into a larger land-use information system called multipurpose cadastre for 3D cadastral purposes in a later stage. To this purpose, the chapter investigates 3D planning regulations and distinguishes the potential planning regulations that can be mapped or visualised into 3D zoning only based on planning information. In addition, for a case study (i.e., Victoria, Australia), this chapter showcases an enriched 3D zoning for five identified planning regulations including height limits, noise impacts, side and rear setbacks, street setbacks (side and front), and flooding limits. The showcase aims to support our discussion regarding mapping planning regulations for cadastral purposes (e.g., a building subdivision and defining new ownership boundaries). Finally, the conclusions derived through this study were addressed by presenting issues that require further research.

3.4 Building Subdivision Process in Victoria, Australia

To support our discussion and understand the current practices and existing issues and challenges, Victorian jurisdiction in Australia is selected as a case study. A building subdivision process in Victoria includes four main phases namely planning, certification, compliance, and registration phases (Atazadeh, 2017; Shojaei, 2014). In the planning phase, as the focus of this chapter, the proposed design must be approved mainly based on the Victorian planning scheme. The planning scheme, as a legal document, is developed mainly based on Planning and Environment Act(1987), Victoria, Australia. Generally, this planning system regulates “use” and “development” on land by zoning and planning regulations and includes different components such as zones, overlays, Local Planning Policy Framework (LPPF), State Planning Policy Framework (SPPF), general provisions, particular provisions, and schedules.

For a proposed development on a vacant land parcel, the process starts when an owner or a developer identifies an appropriate piece of land for the development. Accordingly, a land surveyor determines the boundaries of land by conducting a site survey and an architect designs the architectural model for the new “development” on the land parcel. The proposed development must be approved based on the Victorian planning scheme and the authority that administrates the planning scheme would be the responsible authority for granting/refusing the permit. In most cases, a city council is a responsible authority and the first point of contact for planning permit applications.

The decision-making stage starts when an application including plans, supporting information, and a copy of the title is submitted to the responsible authority (i.e., council) to get a planning permit or amend an existing permit.

In summary, the decision-making stage mainly consists of three steps including referring an application to referral authority (e.g., utility suppliers such as water, electricity, and broadband network), asking for further information, and verifying the application mainly based on the planning scheme ordinance. The responsible authority needs to assess the planning permit application by verifying zoning and planning regulations. After verifying planning and zoning regulations, which usually takes 60 days (excluding additional information requests that can make a delay in the whole process), the responsible authority notifies owners about the potential zoning and planning regulations conflicts.

After receiving the planning permit, the land surveyor prepares subdivision plans based on the architectural design to apply for certifying subdivision plans (i.e., certification phase). This phase can be done concurrently with the planning phase. It should be noted that the certification phase verified by the Subdivision Act (1988) and Regulations (2011) is not the focus of this chapter. It should also be noted that this chapter only considers available planning regulations for building one, two or more dwellings on a lot, residential buildings, apartments with less than five storeys, and apartments containing five or more storeys.

3.5 3D Zoning and 3D Cadastre

Several software development companies (e.g., ESRI, Archistar[8], Gridics[9], MODELUR[10]) and cities (e.g., Toronto[11], Vancouver[12], Washington D.C[13], City of Miami) are launching their first version of 3D zoning mainly containing a 3D representation of some zoning and planning regulations such as height and setback limits (Quick et al., 2019; Schaller et al., 2015). However, in addition to not being fully operational and accessible, identifying potential zoning and planning regulations that can be represented in 3D zoning as well as its linkage with 3D cadastral purposes are still lacking and need further investigations.

Currently, in Victoria, Australia, checking the compliance of land with planning regulations before designing and defining new ownership boundaries when subdividing multi-owned buildings is not reachable unless surveyors lodge an application for a planning permit to a responsible authority (e.g., city council) (Atazadeh, 2017; Emamgholian et al., 2021a, 2020a). However, to give an impression to the architects and land surveyors to design and subdivide proposed developments in accordance with the planning regulations, potential planning regulations can be mapped or represented in 3D by enriching 3D zoning. In this way, 3D zoning as the missing piece can link planning regulations with 3D cadastre by specifying usable and restricted spaces in the domain

[8] https://archistar.ai/
[9] https://gridics.com/zoning-data-api/
[10] https://modelur.com/
[11] https://map.toronto.ca/maps/map.jsp?app=TorontoMaps_v2
[12] https://www.reddit.com/r/MapPorn/comments/83g7i7/interactive_3d_zoning_map_of_vancouver_canada/
[13] https://maps.dcoz.dc.gov/3D/

of land administration. In addition to being used for several cadastral purposes such as subdividing multi-owned buildings and defining new ownership boundaries, it can also be integrated into a larger land-use information system called multipurpose cadastre to find better compliance between land use, urban planning, and citizen welfare.

To this purpose, after exploring the characteristics of planning regulations, we propose three groups of 3D planning regulations to identify the potential planning regulations enriching 3D zoning. These groups include: 1) proposed design needed, 2) 3D city model needed, and 3) 3D zoning groups. The main distinction between these groups is whether physical objects are required either in the new development proposal or in surrounding buildings to map or represent these regulations into 3D zoning. Each group with several examples is discussed in detail as follows. It should be considered that this chapter focuses on city-scale 3D regulations and does not discuss internal restricted and usable spaces.

3.5.1 Proposed Design Needed

The first group as specified in Table 3.1 includes 3D planning regulations (including their short description) for which the proposed development design model is required to map or visualise. Since the proposed design is required, these planning regulations cannot be represented in 3D zoning platforms unless we have access to the design model of the proposed development. However, they can be checked by architects and land surveyors after designing and subdividing multi-owned buildings whenever surrounding buildings are not required. This group is not the focus of this study and the importance of having the design model of new developments on modelling planning regulations (e.g., BIM data with sufficient Level Of Development (LOD)) is discussed in Emamgholian et al. (2021a).

Table 3.1 – Planning regulations in proposed design needed group

<table>
<tr><th>Group</th><th>Planning Regulations</th><th>Short Description</th><th>Design model of proposed developments</th><th>Surrounding buildings</th></tr>
<tr><td rowspan="6">Proposed design needed</td><td>Overlooking</td><td>A habitable room window, balcony, terrace, deck, or patio of a proposed building must not provide a direct line of sight into the secluded private open space and habitable room windows of existing buildings.</td><td rowspan="6">Required</td><td>Required</td></tr>
<tr><td>Daylight to New Windows</td><td>Habitable room windows of proposed buildings should provide a light court (or outdoor space) with a minimum area of 3 square meters and a minimum dimension of 1 meter clear to the sky.</td><td>Required</td></tr>
<tr><td>Internal Views</td><td>Windows and balconies should not cause an overlooking of more than 50 percent of the secluded private open space of a lower-level residential building directly below and within the same development.</td><td>Not required</td></tr>
<tr><td>Energy Efficiency Protection</td><td>It considers the effects of overshadowing on an existing rooftop solar energy system on an adjoining lot.</td><td>Required</td></tr>
<tr><td>Solar Access to Open Space</td><td>The southern boundary of secluded private open spaces of proposed buildings should be set back from all walls on the north, at least (2 + 0.9h) meters (‘h’ is the height of the wall).</td><td>Not required</td></tr>
<tr><td>Overshadowing Open Space</td><td>In this case, overshadowing on existing secluded private open spaces will be checked.</td><td>Required</td></tr>
</table>

3.5.2 3D City Model Needed

The second group as specified in Table 3.2 includes 3D planning regulations (including their short description) for which the design model of the proposed development is not required but 3D models of surrounding buildings are required. Although these regulations do not necessarily require a design model of the proposed development, for enriching 3D zoning platforms with them, the 3D models of surrounding buildings are required. This is where having 3D city models with existing buildings and city furniture matters. In this case, the planning regulations can be mapped in 3D zoning only if it is combined with the 3D city model. The approach and benefits of combining the 3D city model with planning regulations and a detailed discussion about the importance of having a 3D city model (e.g., CityGML data with a sufficient Level of Detail (LoD)) for mapping planning regulations can be found in Emamgholian et al. (2021a). It can be concluded that for the planning regulations that require the 3D model of surrounding buildings, like those listed in Table 3.2, it is possible to enrich the 3D zoning with them only if a 3D city model including existing buildings is accessible.

Table 3.2 – Planning regulations in 3D city model needed group

Group	Planning Regulations	Short Description	Design model of proposed developments	Surrounding buildings
3D city model needed	**Daylight to Existing Windows**	Proposed buildings should provide a light court (or outdoor space) to the existing (adjoining) habitable room windows with a minimum area of 3 square meters and a minimum dimension of 1 meter clear to the sky.	Not required	**Required**
	Buildings Separation	It considers minimum distances between proposed buildings and existing buildings.	Not required	
	North-facing Windows	It considers if a north-facing habitable room window of an existing building is within 3 meters of a boundary on a proposed building's boundary, the proposed building should be setback from its boundary.	Not required	
	Depth Limitation[14]	It restricts any structure to be built over or near any of underground assets or easements.	Not required	

3.5.3 3D Zoning

The third group as specified in Table 3.3 includes 3D planning regulations (including their short description) for which neither the design model of the proposed development nor surrounding buildings is required. This group with the capability of being mapped in 3D zoning seems to be the most valuable one to achieve the overall objective (i.e., enriching 3D zoning to enable visualising restricted and usable spaces for cadastral purposes). In this case, 3D zoning potentially can be enriched with a 3D representation of the planning regulations to be linked with 3D cadastral purposes (e.g., subdividing multi-owned buildings and defining new ownership boundaries). It should be noted that this chapter does not discuss the geometric modelling stage of specified planning regulations. The modelling parameters and geometric modelling approaches for representing 3D planning regulations are discussed thoroughly in Emamgholian et al. (2021a).

[14] Although this regulation does not need the design model of surrounding buildings, it requires some underground assets (e.g., sewer pipes) in 3D city models.

Table 3.3 – Planning regulations in 3D zoning group

Group	Planning Regulations	Short Description	Design model of proposed developments	Surrounding buildings
3D zoning	**Height Limits**	It considers the vertical distance between the ground level and the top of the proposed development.	Not Required	
	Side and Rear Setbacks	Proposed buildings should be set back from side or rear boundaries not less than the distance specified in the planning scheme or schedule.		
	Street Setbacks	Proposed buildings should be set back from side or front boundaries adjacent with streets not less than the distance specified in the planning scheme or schedule.		
	Noise Impacts	Residential buildings and dwellings close to busy roads, railway lines, or industry should be designed in a way that limits noise levels in habitable rooms.		
	Flooding Limits	Openings including doors, windows, and entrance level should be designed in an accordance with flooding limits.		

3.6 Showcase

To support our discussion regarding mapping planning regulations for cadastral purposes, this section presents a showcase for five planning regulations specified in the 3D zoning group (i.e., Table 3.3) including height limits, side and rear setbacks, street setbacks, noise impacts, and flooding limits. In this showcase, land administration and planning authorities are the lead beneficiary of 3D zoning. In addition, 3D representation of planning regulations can give an impression to the land buyers/developers for their investment and it might affect the value of their property significantly (Calder, 2017; El Yamani et al., 2021; Emamgholian et al., 2020b). Please note that this chapter does not discuss the geometric modeling aspects of planning regulations and this showcase is only a demonstration of an enriched 3D zoning.

This showcase consists of programming inside a web-based application (i.e., Cesium) using JavaScript. 2D zoning base map (in Shapefile format) for the city of Melbourne that is provided by the Department of Environment, Land, Water & Planning (DELWP)[15] was converted to GeoJSON and imported to Cesium ion (Figure 3.1 (a)). To be more precise about mapping usable and restricted spaces, a land parcel (as an example)

[15] https://www.delwp.vic.gov.au/

was selected located in Fishermans Bend precinct (Figure 3.1 (b)). We assume that a multi-owned development is going to be constructed on this land parcel.

(a) (b)

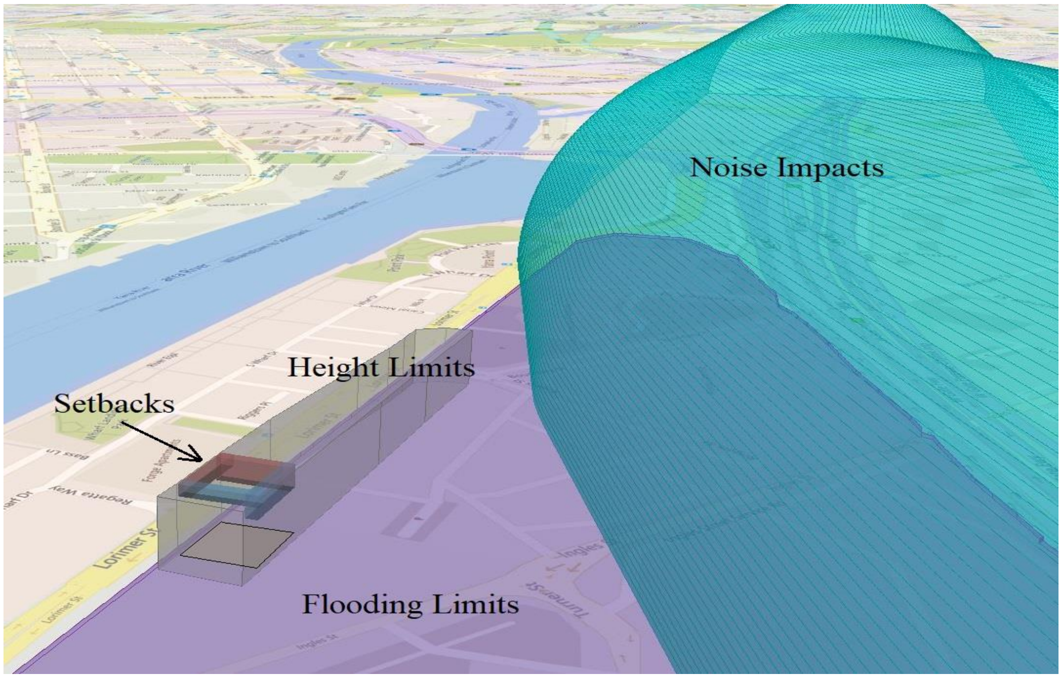
Figure 3.1 – **a)** Part of Melbourne zoning base map (color-coded based on different zones); **b)** The selected land parcel (colored in yellow)

Based on the location of the land parcel and its assigned planning regulations summarised in the planning scheme ordinance[16] and complementary documents and guidelines (e.g., for flooding[17]), 3D zoning is enriched with the selected regulations as follows.

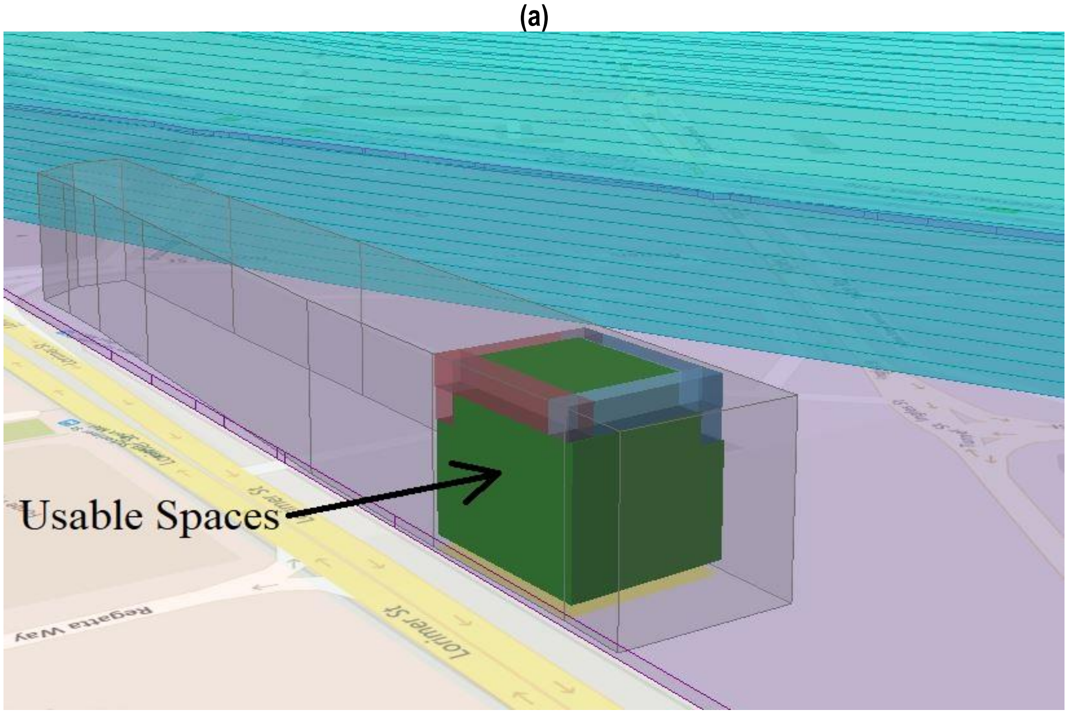
- Height Limits: According to schedule 67 to clause 43.02 design and development overlay related to Fishermans Bend - Lorimer Precinct (Melbourne Planning Scheme Ordinance, p. 907), a height limit of 36 meters applies to this land parcel.
- Street Setbacks (front and side): It is allowed to have a street wall type D (i.e., 8 storeys height) for its front street and type C (i.e., 6 storeys height) for its side street. From that level (i.e., street wall height) up to the height limits, a minimum street setback of 5 meters applies to front and side streets.
- Side & Rear Setbacks: If we assume that where the building below the maximum street wall height is built on the boundary, at least side and rear setbacks of 5 meters must be applied to both side and rear parts of the land parcel.
- Noise Impacts: For noise impacts, the proposed developments' construction materials need additional verifications if it is at less than 300 meters distance from the nearest lane of a freeway.
- Flooding Limits: By considering flooding limits, finished entrance and first floor levels should respect a minimum height limit (based on either predicted 2100 1% Annual Exceedance Probability (AEP) flood level or Nominal Flood Protection Level (NFPL)) to mitigate flooding concerns. Based on the location of this land parcel, 2.4 meters flooding limits are applicable.

Figure 3.2 (a) illustrates enriched 3D zoning specifying the restricted spaces applicable to the land parcel. Accordingly, Figure 3.2 (b) illustrates both restricted and usable spaces for the land parcel.

[16] http://www.melbourne.vic.gov.au/building-and-development/urban-planning/melbourne-planning-scheme/Pages/melbourne-planning-scheme.aspx
[17] https://www.water.vic.gov.au/__data/assets/pdf_file/0025/409570/Guidelines-for-Development-in-Flood_finalAA.pdf



(a)



(b)

Figure 3.2 – Mapping restricted spaces into 3D zoning by **a)** height limits (colored in grey), front and side street setbacks (colored in orange), side and rear setbacks (colored in blue), noise impacts (colored in cyan), and flooding limits (colored in purple); **b)** Usable spaces applicable in the land parcel (colored in green).

3.7 Discussion and Conclusion

In this chapter, we argued that to have a multipurpose cadastre, 3D zoning enriched with a 3D representation of 3D planning regulations has a great potential to be integrated into a larger land-use information system called a multipurpose cadastre system. Land administration and planning authorities can benefit from such a system by having access to the restricted and usable spaces in a literally more visual way. To this purpose, planning regulations were categorised into three groups including proposed design needed, 3D city model needed, and 3D zoning. Planning regulations in the 3D zoning group with the capability of being mapped by reaching only planning information was the most potential one to achieve the overall objective (i.e., integrating planning regulations with 3D cadastre in a larger system called multipurpose cadastre accessible to all parties). After identifying the potential planning regulations, with the purpose of supporting our discussion regarding mapping planning regulations for cadastral purposes, the chapter resulted in a showcase for five regulations including height limits, noise impacts, side and rear setbacks, street setbacks (side and front), and flooding limits.

During this study, some important points can be highlighted as:

- Identifying more potential regulations: 3D zoning should be taken as a basis of a 3D representation of potential regulations depicting usable and restricted spaces in a multipurpose cadastral system. To this purpose, other potential planning regulations, sub-regulations, and other restrictions imposed on city precincts should be added to such a system.
- Qualitative reasoning: Since planning regulations can contain discretionary (e.g., noise impacts) or mandatory (e.g., minimum setbacks) rules, restricted spaces in the 3D zoning do not necessarily mean that they are not usable. This aspect reminds the importance of having qualitative reasoning in later stages.
- Reaching a generic approach: Planning regulations and their restrictions may not only be diverse in different jurisdictions but may also be distinct in different cities. Although the general rules may be the same, it is not straightforward to achieve a generic approach that maps/represents all the limited spaces applicable in all precincts. However, if the difference in the description of the rules is taken into account, the process can still be the same.
- Data linkage and accessibility: The required data (e.g., planning information, zoning base maps, related guidelines) is provided by different organisations with different levels of accessibility. To achieve having an integrated land-use information system including all required data further studies investigating data integration aspects like data quality and standardisation are required.
- 3D city models and BIMs: This study shows that enriching 3D zoning has a great potential to be utilised in land administration systems. It can also facilitate the decision-making process for granting planning/building permits in a later stage. However, as the first step, only one group of planning regulations (i.e., 3D zoning group) could be mapped into 3D zoning. Hence, to represent all restricted spaces, 3D city models and BIMs should also be integrated with the enriched 3D zoning.
- Automatic enrichment: Planning regulations and their related information are mostly summarised in textual documents including lots of complexities that make the automation process fail. It needs further research as well as collaborative work engaging all parties to facilitate the process of enriching 3D zoning automatically.

Chapter 4 – A Conceptual Framework for Automatic Modelling and Conflict Detection of 3D Land-use Regulation Restrictions

This chapter presents a three-stage conceptual framework for automatic 3D modelling and conflict detection of 3D LuRs as the main objective of this thesis. To this purpose, the framework organises the required principles as well as all the IFC required classes/concepts, CityGML required classes/concepts, and most importantly, the planning and zoning requirements. Accordingly, first, the automatic modelling procedure and the proposed level of information need that were discussed for five LuRs in Chapter 2 will be extended to twelve 3D LuRs and take place in the first and second stages of the proposed conceptual framework. Then, this chapter proposes a new category of level of information need with a focus on automating the conflict detection stage. In addition, the classification of LuRs' conflicts proposed in Chapter 1 (i.e., hard and soft conflicts), has been revised in this chapter.

This chapter is the original content of the following paper:

Emamgholian, S., Pouliot, J., Shojaei, D., in review. "A Conceptual Framework for Modelling and Verifying 3D Land-use Regulation Restrictions to Support Land Administration Systems". Submitted to Land Use Policy journal. Submission date: April 9th, 2022.

4.1 Résumé

Il existe une grande variété et diversité de géorèglementations qui aident à règlementer l'utilisation du territoire (qu'on nomme Land-use Regulation-LuR). L'application et donc la validation de ces géorèglementations nécessitent généralement l'utilisation d'analyses spatiales qui vont les combiner avec des éléments du territoire (ex. une rue) ou encore des éléments planifiés (ex. un bâtiment). Ces analyses spatiales peuvent correspondre à des analyses spatiales en 2D (par exemple, le calcul de la superficie) ou encore à d'autres opérations qui nécessitent des analyses plus complexes en 3D (par exemple, l'ombrage et le surplomb). Effectuer ces analyses et vérifications, en particulier à partir de représentation spatiale 3D du territoire, peut s'avérer hasardeux et complexe. Ce chapitre propose un cadre conceptuel, incluant la modélisation 3D des géorèglementations, pour effectuer la détection des conflits qui peuvent survenir entre les éléments du territoire, ou encore les éléments planifiés et ces géorèglementations. Dans le but d'automatiser le plus possible les processus, ce cadre propose différents principes qui cherchent à expliquer comment combiner les géorèglementations 3D avec d'autres sources d'information (par exemple, le zonage 3D, les modèles de ville 3D et le BIM) et les vérifier à l'aide d'analyses spatiales 3D comme l'analyse de proximité. Sur la base d'une étude de cas située dans la ville de Melbourne, Victoria, Australie, les géorèglementations 3D soumises à des approbations de planification et des

subdivisions de nouveaux bâtiments sont examinées. Le chapitre se termine par une discussion sur la faisabilité de l'automatisation de la vérification des géorèglementations afin d'aider à la prise de décision dans les demandes de permis de construire et les subdivisions de bâtiments.

4.2 Abstract

There are a wide variety of Land-use Regulation (LuR) restrictions, ranging from those that need simple 2D spatial analyses to be verified (e.g., area calculation), to those that need complex 3D analyses (e.g., overshadowing and overlooking). Assessing LuR restrictions to detect potential conflicts automatically could be a challenging task in land administration systems relying on 2D drawings and 2D representations especially when 3D/vertical analyses are required. Land administration systems can include 3D representations of LuR restrictions to identify their impacts on land parcels and vice versa since the LuRs contain legally binding restrictions for all parties including governments and citizens. As part of the transition from the 2D representation and manual conflict detection of LuR restrictions towards a 3D digital representation and automatic conflict detection, this chapter proposes a three-stage conceptual framework for automatic 3D modelling and conflict detection of 3D LuR restrictions to support land administration systems. The three-stage conceptual framework, as a generic approach, proposes required principles and procedures to automatically (1) model 3D LuR restrictions (called 3D CityLuR), (2) combine them with other sources of information (e.g., zoning maps, 3D city models, and BIM), and (3) detect LuRs' potential conflicts. For modelling and verifying 3D LuRs automatically, the framework organises all the IFC required classes/concepts, CityGML required classes/concepts, and most importantly, the planning and zoning requirements. Moreover, it proposes two categories of level of information need for (1) modelling and combing 3D CityLuR with other sources of information automatically and (2) detecting LuR restrictions' potential spatio-semantic conflicts automatically. Based on a case study located in the City of Melbourne (where planning activities are under the control of authorities in the state of Victoria, Australia), 3D LuR restrictions subject to planning approvals and building subdivisions are investigated. The chapter concludes by arguing the feasibility of automating the decision-making process to support planning authorities in planning permit and building subdivision processes.

4.3 Introduction

4.3.1 Context and Problematics

The increasing demand for complex residential/commercial developments in rapidly growing cities complicates the processes required for verifying Land-use Regulation (LuR) restrictions (Kitsakis et al., 2022; Olsson et al., 2018; Plazza et al., 2019; Selmi et al., 2017). LuRs including planning restrictions impose major impacts on Rights, Restrictions, and Responsibilities (RRRs) on land administration systems (Asghari et al., 2020; Kitsakis et al., 2019). Land administration can be shortly introduced as land registry, cadastres, valuation, and land-use (planning) in which recently, 3D representation in planning and permitting are getting increasing attention (van Oosterom et al., 2020).

Verifying LuR restrictions could be a challenging task for responsible authorities in land administration systems especially when 3D components (e.g., height, depth, and volume of building elements or 3D LuRs) are involved (Emamgholian et al., 2020a; Faucher and Nivet, 2000; Grimmer, 2007; Guler and Yomralioglu, 2021; Sampaio and Berdeja, 2017; Van Berlo et al., 2013). Land administration needs to be modernised with 3D digital approaches to identify the impacts of 3D LuR restrictions on land parcels and vice versa since the LuRs contain legally binding rules (or restrictions) for all parties including governments and citizens (Emamgholian et al., 2021b; Kitsakis and Dimopoulou, 2017). As a formerly argued concept, modelling and representing LuRs in 3D can facilitate the management of RRRs, and identifying the sufficient level of information need plays a vital role in decision-making for land administration (Emamgholian et al., 2020a, 2021a, 2021b). However, in reviewing the current research and practice, a framework focusing on the identification of the principles, procedures, and requirements for automatic modelling and conflict detection of 3D LuR restrictions is generally lacking (Barzegar et al., 2021; Emamgholian et al., 2021a; Kitsakis and Dimopoulou, 2017; Noardo et al., 2022a, 2020a; Rajabifard et al., 2019).

Currently, in most jurisdictions like Victoria, Australia, checking the compliance of multi-owned buildings with planning restrictions before designing and defining new ownership boundaries is not feasible unless surveyors lodge an application for a planning permit to the responsible authority (e.g., city council) (Atazadeh, 2017; Emamgholian et al., 2021b, 2021a, 2020a). In addition, owners should include all the required information that the responsible authority might need to verify planning restrictions. Otherwise, they might be asked to provide further information that makes a delay in the entire assessment process. Based on Planning Permit Activity Reporting System (PPARS) report extracted from the planning and building approvals process review in Victoria[18] (Figure 4.1), for all new residential permits in the state of Victoria in 2017, almost two-thirds of the applications took more than two months, a quarter more than six months, and nearly one in ten more than ten months to be assessed.

[18] https://www.vic.gov.au/planning-and-building-approvals-process-review

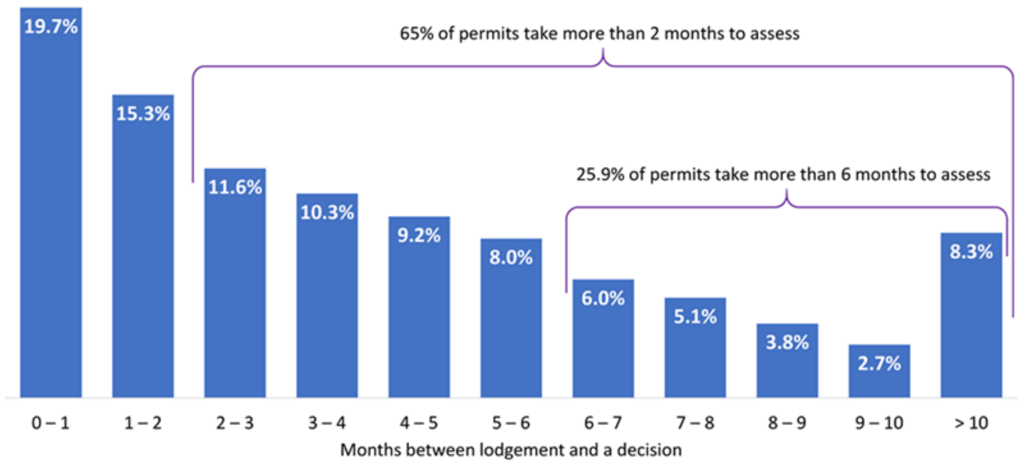


Figure 4.1 – Proportion of permit applications for new residential developments in Victoria, Australia, in 2017[19]

To have a better impression regarding the delay costs, this review based on Australian Bureau of Statistics (ABS), PPARS, and SGS, shows that for around 75,000 residential dwelling units that were approved in 2017, one day accelerating the LuR restrictions' verification process could save AU$7.6 million. In the case of commercial development, it shows that the owners/developers can save AU$50,000 if LuRs assessment process could be improved for only one day for only one commercial development. This estimation is based on the foregone rental yield that residential and commercial developments could otherwise be expected to generate.

4.3.2 Objectives

This study is part of a research project started in 2019 in collaboration between Université Laval (Centre for Research in Geospatial Data and Intelligence) and the University of Melbourne (Centre for SDIs and Land Administration) to address the problem of modelling 3D LuRs and detecting their potential spatio-semantic conflicts automatically by considering intended users' needs. As the first phase of this project, the magnitude of potential LuR conflicts was classified into two groups namely hard and soft conflicts in which the 3D spatial configuration of LuRs was one of the prominent variables to assess 3D LuRs (Emamgholian et al., 2020a). As the second phase of the project, an investigation regarding how 3D LuRs can be modelled and combined with 3D zoning and 3D city models to support decision-making in planning approval and building subdivision processes was conducted (Emamgholian et al., 2021a, 2021b). Accordingly, as the third phase of this project, the main objective of this chapter is to propose a three-stage conceptual framework for automatic 3D modelling and conflict detection of 3D LuR restrictions to support land administration systems.

The three-stage conceptual framework, as the main contribution of this chapter, organises and proposes a generic procedure for managing/interacting with 3D LuR restrictions leading to detecting LuRs' potential conflicts

[19] https://www.vic.gov.au/planning-and-building-approvals-process-review

automatically. The framework's first stage, focusing on the automatic modelling of 3D LuR restrictions geometrically, aims to identify modelling key parameters representing LuRs' extent (mainly from planning scheme ordinance and planning documents). This stage then aims to propose a geometric modelling approach based on the identified key parameters to model LuR restrictions automatically (called 3D CityLuR). The second stage, namely combination, aims to combine 3D CityLuR with other sources of information automatically. To this purpose, it proposes the level of information need for combining 3D CityLuR with other sources of information automatically. It should be noted that the second stage does not consider the conflict detection requirements and only focuses on instantiating 3D LuR restriction automatically within 3D city models. Finally, the last stage, namely conflict detection, aims to automate the process of detecting 3D LuRs' potential conflicts that might arise between LuR restrictions and physical objects like building elements. For this purpose, this stage proposes a new category of level of information need for detecting potential spatio-semantic LuRs' conflicts automatically.

4.3.3 Methodology

This chapter focuses on developing a conceptual framework that formalises principles and requirements for automating the process of modelling 3D LuRs and detecting their potential conflicts. This framework helps to identify key modelling parameters, best geometric modelling approaches, and the required information (as the level of information need) to model and verify LuR restrictions automatically. Accordingly, this chapter follows qualitative methods including literature review, selecting a use case and case study (i.e., planning permit and building subdivision in the City of Melbourne in Victoria, Australia), and meetings (with planning authorities at DELWP). In this chapter, twelve 3D LuRs subject to planning approvals proposed by Emamgholian et al. (2020a) will be discussed thoroughly. The next section summarises the planning permit and building subdivision processes in Victoria, Australia, followed by inventorying the selected 3D LuR restrictions. Section 4.5 presents the proposed conceptual framework for automatic modelling and conflict detection of 3D LuRs followed by a discussion on classifying conflicts to support the decision-making stage (section 4.5.5). Finally, the conclusions derived from this study are addressed by discussing issues that require further research (section 4.6).

4.4 LuRs with 3D Components in Planning Permit and Building Subdivision Processes

4.4.1 Planning Permit and Building Subdivision Processes in Victoria

To have a better impression and narrow down the scope of the investigation, this chapter focuses on the planning permit and building subdivision processes in Victoria, Australia. The selected use-cases, planning permits and building subdivision processes, were identified as the most useful use cases for further investigation in the literature based on users' needs in which various 3D LuRs can be applied (Benner et al., 2010; Hobeika et al., 2021; Noardo et al., 2020a, 2019; Olsson et al., 2018; Shin et al., 2022; Van Berlo et al., 2013).

The building subdivision process in Victoria includes four main phases namely planning, certification, compliance, and registration phases (Atazadeh, 2017; Olfat et al., 2019; Shojaei, 2014). In the planning phase, as the focus of this chapter, the proposed design must be approved mainly based on the Victorian planning scheme. The planning scheme, as a legal document, is developed mainly based on Planning and Environment Act (1987), Victoria, Australia. Generally, this planning system regulates "use" and "development" on land by zoning and planning regulations and includes different components such as zones, overlays, Local Planning Policy Framework (LPPF), State Planning Policy Framework (SPPF), general provisions, particular provisions, and schedules.

For a proposed development on a vacant land parcel, the process of proposing new developments starts when an owner or a developer identifies an appropriate piece of land for the development. Accordingly, a land surveyor determines the boundaries of land by conducting a site survey and an architect designs the architectural model for the new "development" on the land parcel. The proposed development must be approved based on the Victorian planning scheme and the authority that administrates the planning scheme would be the responsible authority for granting/refusing the permit. In most cases, a city council is a responsible authority and the first point of contact for planning permit applications. It should be noted that the minister for planning can also be the responsible authority (e.g., for buildings containing a total gross floor area of more than 25,000 square metres[20]).

The decision-making stage starts when an application including plans, supporting information, and a copy of the title is submitted to the responsible authority (i.e., council) to get a planning permit or amend an existing permit. In summary, the decision-making stage mainly consists of three steps including referring an application to referral authorities (e.g., utility suppliers such as water, electricity, and broadband network), asking for further information, and verifying the application mainly based on the planning scheme ordinance. The responsible authority needs to assess the planning permit application by verifying LuR restrictions subject to planning approvals and building subdivisions. After verifying LuR restrictions, which usually takes 60 days (excluding additional information requests that can make a delay in the whole process), the responsible authority notifies owners about the potential LuRs' conflicts (if any).

After receiving the planning permit, the land surveyor prepares subdivision plans based on the architectural design to apply for certifying subdivision plans (i.e., certification phase). This phase can be done concurrently with the planning phase (Atazadeh, 2017). It should be noted that the certification phase verified by the Subdivision Act (1988) and Regulations (2011) is not the focus of this chapter.

[20] https://planning-schemes.api.delwp.vic.gov.au/schemes/melbourne/ordinance/72_01s_melb.pdf?_ga=2.159160890.181099385.1608159523-41528895.1580184711

4.4.2 LuR Restrictions Comprising 3D Components

To ensure a good understanding of what is LuR with 3D components, this section describes twelve relevant LuR restrictions subject to planning approval in Victoria. The descriptions are presented in a form that contextualise the understanding of the principles and the procedure of automatic 3D modelling and conflict detection of these LuRs in the coming sections. It should be noted that these LuR restrictions in Victoria are applicable for constructing one, two, or more dwellings on a lot, residential buildings, apartments with less than five storeys, and apartments containing five or more storeys.

1) **Building Height Limits:** It considers the vertical distance between the ground level and the top of the proposed development.
2) **Side and Rear Setbacks:** It considers that proposed buildings should be set back from side or rear boundaries not less than the distance specified in the planning scheme or schedule (**Case 1**). If it is not specified, not less than 1 meter, plus 0.3 meters for every meter of height over 3.6 meters up to 6.9 meters, plus 1 meter for every meter of height over 6.9 meters (**Case 2**).
3) **Street Setbacks:** It considers that proposed buildings should be set back from side or front boundaries adjacent with streets not less than the distance specified in the planning scheme or schedule.
4) **North-facing Windows:** It considers if a north-facing habitable room window of an existing building is within 3 meters of a boundary on a proposed building's boundary, the proposed building should be setback from its boundary.
5) **Energy Efficiency Protection:** It considers the effects of overshadowing on an existing rooftop solar energy system on an adjoining lot.
6) **Overshadowing Open Space:** In this case, overshadowing on existing secluded private open spaces will be checked.
7) **Solar Access to Open Space:** The southern boundary of secluded private open spaces of proposed buildings should be set back from all walls on the north, at least (2 + 0.9h) meters ('h' is the height of the wall).
8) **Daylight to Existing Windows:** Proposed buildings should provide a light court (or outdoor space) to the existing (adjoining) habitable room windows with a minimum area of 3 square meters and a minimum dimension of 1 meter clear to the sky (**Case 1**). Moreover, the walls (in boundary) of the proposed development with a height more than 3 meters next to an existing habitable room window should be set back at least half of the height of the new wall if the wall is within a 55-degree arc from the centre of the existing window (**Case 2-1**). The arc can be swung to within 35 degrees (**Case 2-2**).
9) **Daylight to New Windows:** Habitable room windows of proposed buildings should provide a light court (or outdoor space) with a minimum area of 3 square meters and a minimum dimension of 1 meter clear to the sky.
10) **Overlooking:** It considers that a habitable room window, balcony, terrace, deck, or patio of a proposed building must not provide a direct line of sight into the secluded private open space and habitable room windows of existing buildings.
11) **Noise Impacts:** It considers that residential buildings and dwellings close to busy roads, railway lines, or industry should be designed in a way that limits noise levels in habitable rooms.
12) **Flooding Limits:** It considers that openings including doors, windows, and entrance level should be designed in an accordance with flooding limits.

4.5 Conceptual Framework for Automatic 3D Modelling and Conflict Detection of 3D LuR Restrictions

4.5.1 Underlying Principles of Conceptual Framework

To have 3D modelled LuR restrictions as part of the current representation of the physical world and be able to detect LuRs' potential conflicts, a three-stage conceptual framework for which the automation is on target is proposed (Figure 4.2): 1) Modelling 3D LuR restrictions, 2) Combining 3D LuR restrictions with other sources of information, and 3) Detecting 3D LuRs' conflicts between modelled LuRs and physical objects.

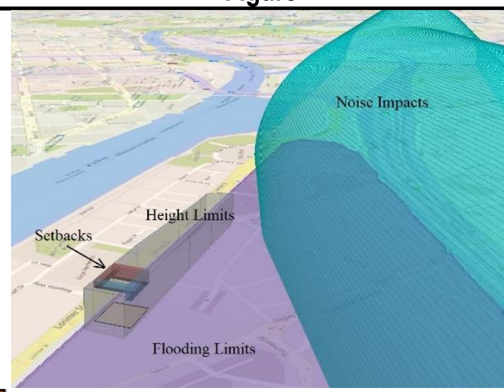
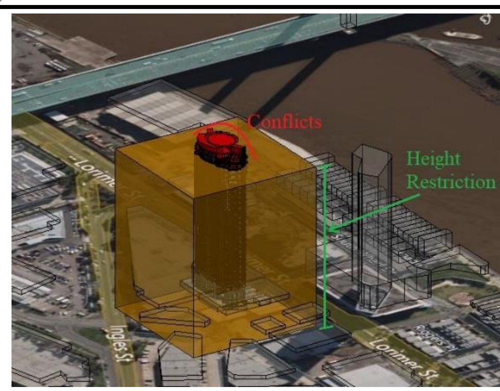
<table>
<tr><th>Stage</th><th>Figure</th></tr>
<tr><td>1- Modelling 3D LuR restrictions</td><td>
</td></tr>
<tr><td>2- Combining 3D LuR restrictions with other sources of information</td><td>
</td></tr>
<tr><td>3- Detecting 3D LuRs' Conflicts between Modelled LuRs and Physical Objects</td><td>
</td></tr>
</table>

Figure 4.2 – The conceptual framework for automatic 3D modelling and conflict detection of 3D LuR restrictions

This framework, as the key contribution of this chapter and an essential supporting decision-making structure, provides principles and required procedures to model 3D LuR restrictions automatically (called 3D CityLuR), combine them with other sources of information (e.g., zoning maps, BIM, 3D city models, and planning information), and detecting their potential conflicts automatically. As the first key principle, the framework proposes to form the modelled 3D LuRs (called 3D CityLuR) outside the model and then combine it with other sources of information. There are numerous contributing factors to this, as follows:

- To keep the framework generic as much as possible without restricting it to a single data model (e.g., IFC or CityGML), it needs to make it possible that the modelled 3D LuRs (called 3D CityLuR) to be combined with any format of 3D models (e.g., IFC, CityGML, FBX, RVT, SHP, DGN). In this way, 3D CityLuR is independent of CityGML or IFC and it can be combined with any other kind of data.
- Generally, IFC and CityGML are formed for supporting physical objects like building elements (Atazadeh, 2017). They use LODev and LoD to show the complexity of 3D models in different aspects such as geometries and semantics that do not necessarily incorporate the concept of LuRs (Emamgholian et al., 2021a; Noardo et al., 2022a).
- As will be discussed in section 4.5.2, modelling LuR restrictions requires using multiple geometric modelling approaches on city-scale that make it nearly impossible to model them within 3D city models like CityGML that uses B-Rep, or BIM which is a suitable geo-context for representing one or a limited number of buildings.
- Finally, there is no need to store and keep the modelled LuR restrictions for the long term since after detecting LuR conflicts, the LuRs are no longer required.

As the second key principle behind this framework that will be discussed in sections 4.5.3 and 4.5.4, the proposed framework uses the concept of level of information need in the two stages of the framework to specify/formalise the requirements for combining 3D CityLuR with other sources of information and detecting 3D LuRs' conflicts automatically. Information requirement as "level of information need" is not a new concept and is discussed in EN ISO 19650 series and BS EN 17412-1 with a focus on BIM. But, in this chapter, the proposed framework proposes the level of information need for the first time for a purpose beyond BIM applications which is automatic 3D modelling and conflict detection of 3D LuRs. The main reason for proposing the level of information need concept is that the concept of LoD in 3D city models and LODev in BIMs, do not consider planning/zoning requirements and cannot fully guarantee that the modelling or compliance checking tasks can be done automatically without the need for additional information.

4.5.2 Modelling 3D LuR Restrictions

In this stage, to model LuR restrictions automatically, key parameters and selected geometric modelling approaches are proposed for all the twelve 3D LuRs. For simplicity, the LuR restrictions are categorised into four groups namely zoning and dimensioning, overshadowing, solar access and viewshed, and environmental LuRs (Tables 4.1 to 4.4). Emamgholian et al. (2021a) have highlighted the modelling aspects of five of these

LuRs namely building height limits, energy efficiency protection, overshadowing open space, overlooking, and noise impacts. However, in this chapter, all the twelve LuRs have been placed in the first stage of the conceptual framework with a detailed discussion regarding the conflict detection stage.

From modelling perspective, the modelling parameters might vary in a specific case based on the LuR restrictions in that area (e.g., setback or height limits are not the same for every precinct). However, the modelling approach and procedure will remain the same. For example, as discussed in section 4.4.2 for side and rear setbacks limits, Wrs and Wss of proposed developments located in different planning zones can be different in case 1. However, in case 2, the parameters are constant, and the setbacks can be modelled by using the union operator through three cuboids and three triangular prisms for side (i.e., **side cube (sc) 1:** Lss, Wss1, Hss4, **sc2:** Lss, Wss2-Wss1, Hss4-Hss2, **sc3:** Lss, Wss3-Wss2, Hss4-Hss3, **side triangular prism (stp) 1:** Lss, Wss2-Wss1, Hss2-Hss1, **stp2:** Lss, Wss3-Wss2, Hss3-Hss2, **stp3:** Lss, Wss4-Wss3, Hss4-Hss3) and rear (same modelling parameters as side) parts. It should be noted that the proposed modelling approaches for setbacks here are for rectangular land parcels or those that can be converted to a portion of lines.

Table 4.1 – Zoning and dimensioning 3D LuR restrictions' modelling key parameters and the proposed geometric modelling approach

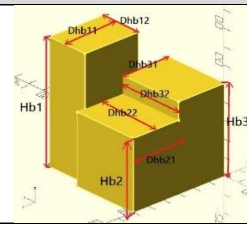
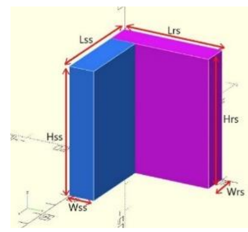
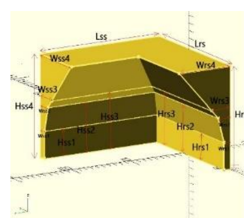
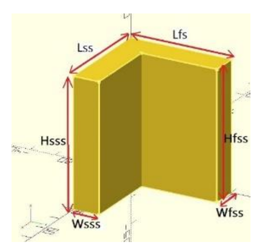
LuR Restriction	Key Parameters	Geometric Modelling Approach	3D Representation
Height Limits	1) Hb (i): height limits in each precinct based on height regulation 2) Dhb (ij): planning zones' dimensions on the terrain	**Extrusion:** Extruding 2D polygons by using Hb values	
Side and Rear Setbacks	Case 1: 1) Hss: height limit for side setback (i.e., the considerable height for checking side setback) 2) Hrs: height limit for rear setback (i.e., the considerable height for checking rear setback) 3) Wss: Width limit for side setback 4)Wrs: Width limit for rear setback 5) Lss: Length of side's lot boundary of proposed development 6) Lrs: Length of rear's lot boundary of proposed development	**CSG:** Rear cuboid (Lrs, Wrs, Hrs) **U** Side cuboid (Lss, Wss, Hss)	
	Case 2: 1) Hss (i): height limits for side setbacks (i.e., the considerable height for checking side setback) 2) Hrs (i): height limits for rear setbacks (i.e., the considerable height for checking rear setback) 3) Wss (i): side setbacks width limits based on side setback regulation. 4) Wrs (i): rear setbacks width limits. 5) Lss: length of side's lot boundary of proposed development 6) Lrs: length of rear's lot boundary of proposed development	**CSG:** (side cube (sc) 1 **U** sc2 **U** sc3 **U** side triangular prism (stp) 1 **U** stp2 **U** stp3) **U** (rear cube (rc) 1 **U** rc2 **U** rc3 **U** rear triangular prism (rtp)1 **U** rtp2 **U** rtp3)	
Street Setbacks	1) Hsss: height limit for side street setback (i.e., the considerable height for checking street setbacks) 2) Hfss: height limit for front street setback (i.e., the considerable height for checking street setbacks) 3) Wsss: width limit for side street setback 4) Wfss: width limit for front street setback 5) Lss: length of side's lot boundary of proposed development 6) Lfs: length of front's lot boundary of proposed development	**CSG:** Front cuboid (Lfs, Wfss, Hfss) **U** Side cuboid (Lss, Wsss, Hsss)	

Table 4.1 – Zoning and dimensioning 3D LuR restrictions' modelling key parameters and the proposed geometric modelling approach

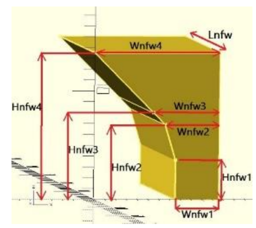
LuR Restriction	Key Parameters	Geometric Modelling Approach	3D Representation
North-facing Windows	1) Hnfw (i): height limits for north-facing windows (i.e., the considerable height for checking north-facing windows) 2) Wnfw (i): width limits based on north-facing windows regulation 3) Lnfw: Length of southern lot boundary of proposed development	**CSG:** cube1(Lnfw, Wnfw1, Hnfw4) **U** cube2(Lnfw, Wnfw2-Wnfw1, Hnfw4-Hnfw2) **U** cube3(Lnfw, Wnfw3-Wnfw2, Hnfw4-Hnfw3) **U** triangular prism (tp) 1 (Lnfw, Wnfw2-Wnfw1, Hnfw2-Hnfw1) **U** tp2(Lnfw, Wnfw3-Wnfw2, Hnfw3-Hnfw2) **U** tp3(Lnfw, Wnfw4-Wnfw3, Hnfw4-Hnfw3)	

Table 4.2 shows that both energy efficiency protection and overshadowing open space need the volumetric shadow to be verified. For skipping the extraction of proposed development geometries, and since currently, 2D shadow on the terrain is mostly available, top-related points can be extracted by using a reverse engineering approach and the notion of sun rays. The oblique distance for tracking sun rays along the sun's direction can be obtained by having access to the proposed development's geographical location as proposed by Emamgholian et al. (2021a). Since the shadows heavily depend on complexity of proposed developments' shapes, it can be modelled by using the Boundary Representation (B-rep) modelling approach (Table 4.2).

Table 4.2 – Overshadowing 3D LuR restrictions' modelling key parameters and the proposed geometric modelling approach

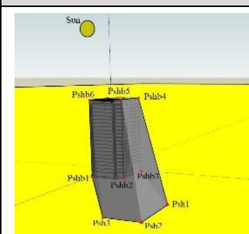
LuR Restriction	Key Parameters	Geometric Modelling Approach	3D Representation
Energy Efficiency Protection	1) Psh (i): corner points of the proposed building's shadow on the terrain (or points of proposed building's shadow with a pre-defined threshold in more complex shadows) 2) Pshb (i): related points of the proposed building façade causing a shadow on the terrain	**B-Rep:** By using the notion of sun rays for Psh (i) points, Pshb (i) points can be extracted	
Overshadowing Open Space			

Table 4.3 shows 3D LuR restrictions related to solar access and viewshed. For example, as indicated in section 4.4.2, daylight to existing windows can have three forms. While case 1 can be modelled by using a solid modelling approach, case 2 utilises the Constructive Solid Geometry (CSG) approach. For example, in case 2-1, first, an intersect operator can be used for two cubes for which cube 2 is rotated RZdew (i.e., 62.5°) along the Z-axis. Second, by repeating the former procedure for cube 3 and cube 4 and translating (i.e., TRdew) and rotating (i.e., RYdew) their intersection, a union operator can generate the final 3D spatial configuration of this LuR (Table 4.3).

Table 4.3 – Solar access and viewshed 3D LuR restrictions' modelling key parameters and the proposed geometric modelling approach

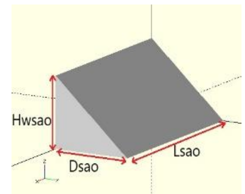
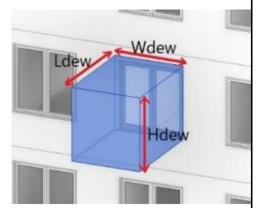
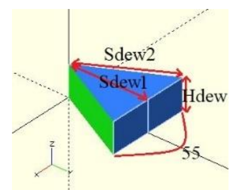
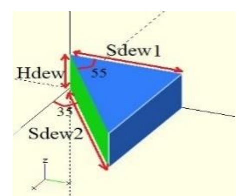
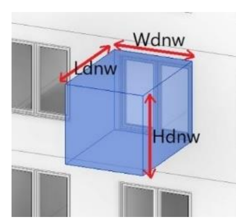
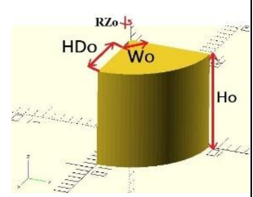
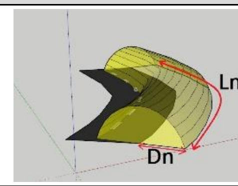
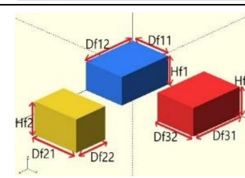
LuR Restriction	Key Parameters	Geometric Modelling Approach	3D Representation
Solar Access to Open Space	1) Lsao: Length of the northern wall boundaries of proposed development 2) Hwsao: Height of the northern wall 3) Dsao: setback distance limit based on solar access to open space regulation (0.9*Hwsao + 2) meters	**Solid modelling:** Triangular prism (Lsao, Dsao, Hwsao)	
Daylight to Existing Windows	Case 1: 1) Wdew: width of existing windows 2) Ldew: length of a light court (or outdoor space) = (3 sqm ÷ Wdew) 3) Hdew: height of a light court (or outdoor space)	**Solid modelling:** Cuboid (Ldew, Wdew, Hdew)	
	Case 2-1: 1) Sdew1: wall setback limits. 2) Sdew2: Sdew1/cos (θ = 55/2˚) 2) Hdew: existing window height 3) RZdew: 62.5˚ rotation along the Z-axis for cube 2 4) TRdew = (0, 0, Hdew) translation of cube 3 ∩ 4 5) RYdew =180˚ rotation of cube 3 ∩ 4 along the Y-axis	**CSG:** (cube 1 ∩ cube 2) **U** [(RYdew) (TRdew) (cube 3 ∩ cube 4)] Cube 1(Sdew1, Sdew1, Hdew), Cube 2(Sdew2, Sdew2, Hdew)	
	Case 2-2: 1) Sdew1: wall setback limits. 2) Sdew2: Sdew1/cos (θ = 55˚) 2) Hdew: existing window height 3) RZdew: 35˚ rotation along the Z-axis for cube 2	**CSG:** (Cube 1 ∩ Cube 2) cube 1(Sdew1, Sdew1, Hdew), cube 2(Sdew2, Sdew2, Hdew)	
Daylight to New Windows	1) Wdnw: Width of new windows 2) Ldnw: Length of a light court (or outdoor space) based on daylight to new windows regulation. This parameter can be calculated based on Wdnw (3 sqm ÷ Wdnw) 3) Hdnw: height of a light court (or outdoor space) based on daylight to new windows regulation	**Solid modelling:** Cuboid (Ldnw, Wdnw, Hdnw)	
Overlooking	1) HDo: horizontal distance limit (i.e., 9 meters) 2) Wo: width of habitable room windows, balconies, terraces, decks, or patios of the proposed building 3) RZo: rotation along the Z-axis 4) Ho: height of the window's floor level	**CSG:** Cylinder (r, h) ∩ Cube (l = w, h) r = HDo + (√2*Wo/2) l = HDo + (√2*Wo/2) h = Ho	

Table 4.4 summarises key parameters and geometric modelling approaches for environmental LuR restrictions. For example, noise impacts can be modelled by sweeping a semicircle with a specified radius along the length of roads or railway lines. The affected distance (i.e., Dn) can vary based on the type of roads or railway lines.

Table 4.4 – Environmental 3D LuR restrictions' modelling key parameters and the proposed geometric modelling approach

LuR Restriction	Key Parameters	Geometric Modelling Approach	3D Representation
Noise Impacts	1) Dn (i): Affected distance 2) Ln (i): Length (of roads or railway lines)	**Sweeping:** Sweeping a semicircle along an irregular path/track	
Flooding Limits	1) Hf (i): flooding height limits in each precinct based on flooding regulation 2) Df (ij): Flood zones' dimensions on the terrain	**Extrusion:** Extruding 2D polygons by using Hf values	

4.5.3 Combining 3D LuR Restrictions with Other Sources of Information

After specifying the modelling key parameters of 3D LuRs and modelling 3D LuRs automatically (called 3D CityLuR) by selecting the geometric modelling approaches, the second stage of the framework focuses on combining 3D CityLuR with other sources of information. To this purpose, this stage defines the first category of level of information need for combining 3D CityLuR with proposed development (e.g., BIM in IFC format) and other sources of information (e.g., planning/zoning maps, and 3D city models in CityGML format). It should be noted that the BIM-GIS integration challenges (e.g., georeferencing BIM design, and converting IFC to CityGML or vice versa) were not addressed here, and it is assumed that this part is already conducted e.g., by using available software solutions.

In this chapter, the level of information need refers to both (1) BIM or 3D city model requirements and (2) required planning information (e.g., zoning base map), to automate 3D modelling and conflict detection of 3D LuR restrictions. To have a better impression of the concepts and principles behind the conceptual framework, if we assume that the proposed development is in IFC format and existing buildings are based on CityGML, Figure 4.3 illustrates a UML class diagram of information requirements for 3D CityLuR including IFC required classes, CityGML required classes, and most importantly, the planning and zoning requirements. The planning and zoning requirements are the essential part of this process since as mentioned before, 3D CityLuR is independent of CityGML or IFC and they can be replaced with any other kind of data but planning and zoning should always be part of the model.

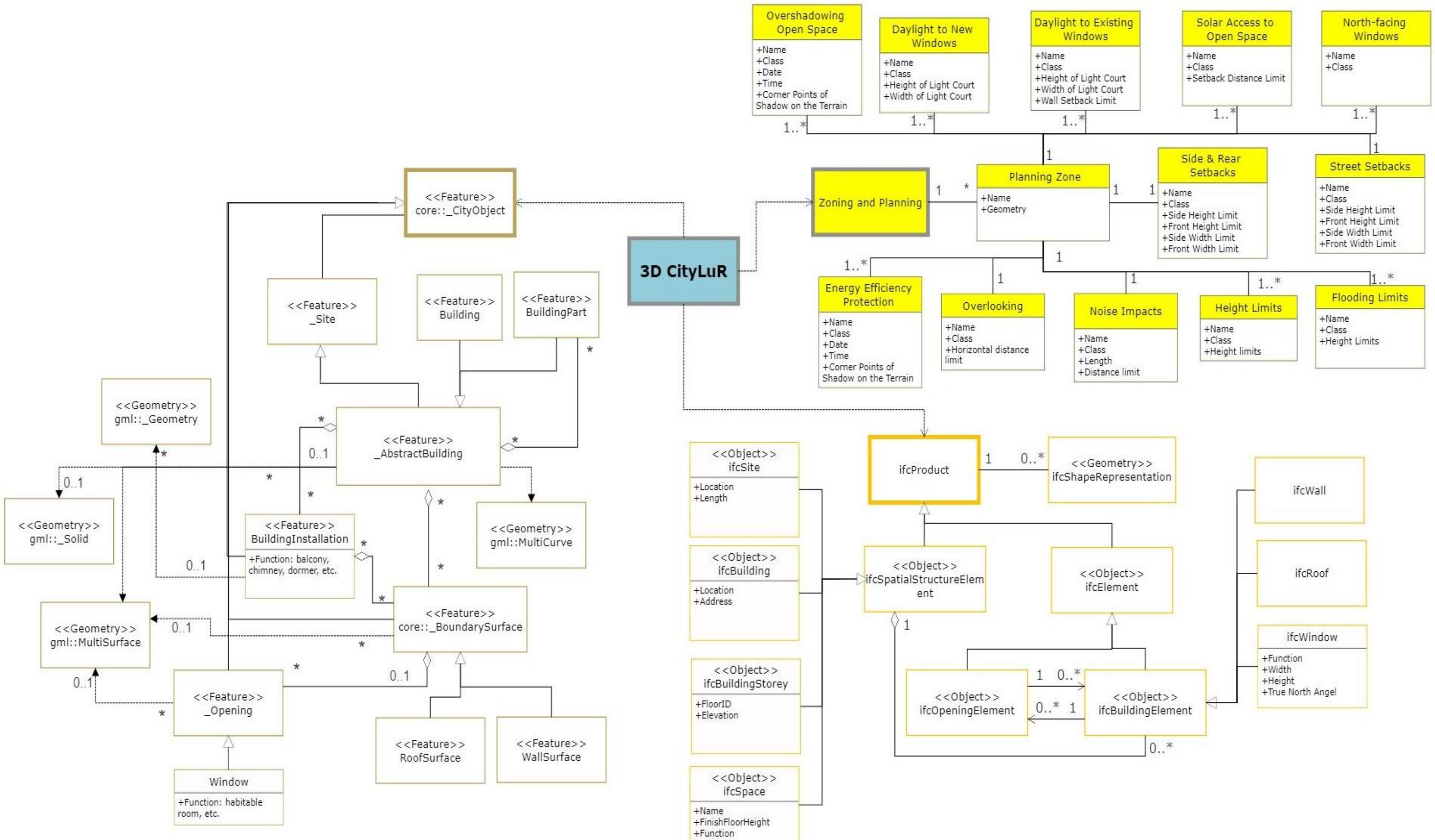


Figure 4.3 – UML class diagram of conceptual model behind the proposed approach for a proposed development in IFC (coloured in orange), existing buildings in CityGML (coloured in tan), and zoning (coloured in yellow).

It should be noted that this diagram shows an excerpt of ifcProduc (adapted from (Donkers, 2013; El-Mekawy et al., 2012)) and Cityobject (adapted from (Donkers, 2013; Lorenzini, 2009)) for the required classes and concepts. To be more specific, as an example, for daylight to existing/new windows, the windows of habitable rooms in existing buildings/proposed developments should be checked to make sure they meet the minimum required light court. Here, as the required information, city data or BIM design should distinguish habitable room windows from other windows (in terms of geometries and semantics). In this case, the required LoD in 3D city models or LODev in BIMs, cannot fully guarantee that the automatic modelling or conflict detection tasks can be done without needing further information since the city data or BIM design might not distinguish habitable room windows from other windows. In addition, sometimes planning information like zoning map restrictions might be needed that is related to neither CityGML LoDs nor BIM LODev (e.g., for modelling height limits).

Table 4.5 specifies the level of information need considering both geometries and semantics (i.e., class of object and attributes). Temporal aspects are considered as part of attributes whenever required (e.g., for overshadowing LuRs). Table 4.5 also indicates the required LODev/LoDs for BIM/CityGML data to compare that in addition to LODev/LoD specifications, still, information requirements need to be specified. A “not required” value for IFC LODev/CityGML LoD does not necessarily mean they can be absent for the entire process, but it emphasises that for the second stage (i.e., combining LuR restrictions with other sources of information) they are not required. However, for the next stage (i.e., verifying 3D LuR restrictions), obviously, a proposed development (e.g., BIM in IFC/RVT format) is always required. It should be noted that this information considers desired circumstances in which 3D LuR restrictions can be modelled and combined with other sources of information automatically.

Table 4.5 – Level of information need and required LODev/LoDs for combining LuR restrictions with BIM and 3D city models

LuR	Required Information as Level of Information Need			Required LODev/LoDs	
	Geometry	Semantic			
		Class of Object	Attribute	IFC LODev	CityGML LoD
Height Limits	Zoning base map (polygon) geometries	-	• Zones' category (road, port, capital city, industrial, etc.) • Height limit	Not required	Not required
Side and Rear Setbacks	Lot boundary edges of proposed development	Lot Boundary/ Wall/ Fence/ Entrance	• Direction (side, rear, etc.)	300	Not required[21]
	Street geometries in zoning base map surrounding proposed development	Street	• Name		
Street Setbacks	Lot boundary edges of proposed development	Lot Boundary/ Fence/ Entrance	• Direction (front, side, etc.)	300	Not required[21]
	Street geometries in zoning base map surrounding proposed development	Street	• Name • Category (i.e., 1,2,3)		
North-facing Windows	Window geometries of existing buildings	Window	• Type (habitable room, etc.) • Floor height	Not required	3
Energy efficiency protection	2D shadow (polygon) geometries of proposed development on the terrain	-	• Belongs to (proposed/existing buildings) • Dates and times (specified dates and times in the planning scheme for checking overshadowing)	300	Not required
Overshadowing Open Space		Shadow			
Solar Access to Open Space	Lot boundary edges of proposed development	Lot Boundary/ Wall	• Wall Height • Axis (north, etc.)	300	Not required
Daylight to Existing Windows	Window geometries of existing buildings	Window	• Function (habitable room, etc.) • Height	300	3
	Lot boundary edges of proposed development	Lot Boundary/ Wall	• Wall Height		
Daylight to New Windows	Window geometries of proposed development	Window	• Function (habitable room, etc.) • Height	300	Not required
Overlooking	Window geometries of proposed development	Window	• Function (habitable room, etc.) • Floor Height	300	Not required
	Balcony/ Terrace/ Patio geometries of proposed development	Balcony/ Terrace/ Patio	• Floor Height		
Noise impacts	Street, railway line, and industry geometries in zoning base map surrounding proposed development	-	• Name of road/ railway line/ industry • Category of road/ railway line	Not required	Not required[22]
Flooding Limits	Zoning base map (polygon) geometries (clamped to the terrain)	-	• Zones' category (port, capital city, industrial, etc.) • Flood height limits	Not required	Not required

[21] LoD 2 is required whenever there are no street geometries in zoning base map surrounding proposed developments

[22] LoD 2 is required whenever there are no street, railway line, and industry geometries in zoning base map surrounding proposed developments

4.5.4 Detecting 3D LuRs' Conflicts between Modelled LuRs and Physical Objects

After modelling 3D LuRs and combining them with other sources of information, the potential conflicts between the modelled LuRs and physical objects like building elements need to be detected. In order to detect the conflicts automatically, planning authorities need specific information within all the sources of data including 3D CityLuR, BIM design of the proposed development, 3D city model of existing buildings, and zoning maps including planning information. In the previous section, the conceptual framework addressed one category of level of information need for modelling 3D LuR restrictions automatically and combining them with other sources of information. The third stage addresses a new category of level of information need for detecting 3D LuRs' conflicts between modelled LuRs and physical objects automatically. Accordingly, Table 4.6 proposes the level of information need considering both geometries and semantics (i.e., class of object and attributes) as well as the required LODev/LoDs for BIM/CityGML data, this time for detecting potential spatio-semantic LuR restriction conflicts automatically. It should be noted that this category differs from the previous one presented in Table 4.5. This category assumes that 3D CityLuR has combined with other sources of information, and it focuses only on the automatic conflict detection requirements.

Table 4.6 – Level of information need and required LODev/LoDs for verifying LuR restrictions

LuR	Required Information as Level of Information Need			Required LODev/LoDs	
		Semantic			
	Geometry	Class of Object	Attribute	IFC LODev	CityGML LoD
Height Limits	Proposed developments' exterior elements geometries such as roofs, walls, gutters, and chimneys	Roof/ Wall/ Gutter/ Chimney/ Flues	• Height	400	Not required
Side and Rear Setbacks	Proposed developments' exterior elements geometries such as walls, balconies, and terraces	Wall/ Balcony/ Sunblind/ Veranda/ Porch/ Eave/ Gutters/ Chimneys/ Flue/ Pipe	-	400	Not required
Street Setbacks	Proposed buildings' exterior elements geometries such as walls, balconies, and terraces	Wall/ Balcony/ Sunblind/ Veranda/ Porch/ Eave/ Gutters/ Chimneys/ Flue/ Pipe	-	400	2
	Lot boundary edges of existing buildings	Lot Boundary/ Fence/ Entrance	• Direction (front, side, etc.)		
North-facing Windows	Lot boundary edges of proposed developments	Lot Boundary/ Wall	• Wall Height • Axis (south, etc.)	300	3
Energy efficiency protection	Rooftop solar energy geometries on existing buildings	Roof/ Solar energy	-	300	3
Overshadowing Open Space	Open space geometries of existing buildings	Open space	• Type (private, public)	300	3
Solar Access to Open Space	Open space geometries of proposed developments	Open space	• Type (private, public)	300	2
Daylight to Existing Windows	Lot Boundary edges of proposed developments	Lot Boundary/ Wall	• Wall Height	300	3
Daylight to New Windows	Lot Boundary edges of proposed developments	Lot Boundary/ Wall	• Wall Height	300	2
Overlooking	Window geometries of existing buildings	Window	• Function (habitable room, etc.)	300	3
	Open space geometries of existing buildings	Open space	• Function (private, public)		
Noise impacts	Window geometries of proposed developments	Window	• Function (habitable room, etc.)	300	3
Flooding Limits	Proposed developments' exterior elements geometries including entrance doors and first floor windows geometries	Door/ Window	• Height or floor height	300	Not required

It should be noted that the conflict detection stage can be done only by considering geometry (e.g., shape, orientation, and location). However, it would be limited to only verifying spatial constraints specified for geometry classes (Stadler and Kolbe, 2007; Wagner et al., 2013). Taking the verification of overlooking restriction as an example, habitable room windows (i.e., geometries and semantics) in the proposed development must not provide a direct line of sight into the existing habitable room windows/private open spaces (i.e., geometries and semantics) located in a distance of closer than 9 meters (i.e., geometry) from them. Therefore, as described in this example, the model should include windows and open spaces of existing buildings (geometries and semantics) as well as their functions as attributes (e.g., habitable room window or public/private open space).

4.5.5 Conflict Classification for 3D CityLuR

After detecting the potential LuRs' potential conflicts, the decision-makers need to decide whether "grant" or "refuse to grant" the permit. Based on the selected case study and through a discussion with planning authorities at DELWP, we noticed that the discretionary or mandatory aspects of 3D LuRs can affect the final decision extensively. Moreover, based on the nature and characteristics of LuRs' detected conflicts, the decision-making might be complicated or even arbitrary in some specific cases. As an example, considering noise impact conflicts, the permit can be issued by restricting the proposed building with a condition to utilise thicker glass for windows within the noise space to reduce the noise impacts in habitable rooms. On contrary, some other 3D LuRs' conflicts like overlooking conflicts need to be strictly avoided since a permit cannot be issued for a proposed building containing overlooking conflicts. With this in mind, fully automating the process of decision-making will be nearly impossible and at some points needs to be done manually. Accordingly, this chapter proposes a revised version of the classification of 3D CityLuR conflicts proposed by Emamgholian et al. (2020a) namely hard and soft conflicts. This classification is based on an inspiration of clash classification in BIM for which hard clashes are costly to be fixed and soft clashes can be fixed easier and do not result in major changes in the BIM design (Matejka and Sabart, 2018). However, the main variable in conflict classification for 3D CityLuR is whether the LuR that causes the conflict is discretionary or mandatory. Accordingly, 3D CityLuR conflicts i.e., the hard and soft conflict classes can be described as follows:

- **Hard Conflict:** It refers to those conflicts that cause a refusal to grant the permit. In this case, the BIM design MUST be revised to address the detected conflicts and a new application MUST be submitted. As an example, overlooking and overshadowing conflicts over secluded private open space result in hard conflicts.
- **Soft Conflict:** It refers to the situations for which planning authorities can grant the permit with some limitations. As an example, with noise impact conflicts, the permit can be issued by utilising thicker glass for windows within the noise space in order to reduce the noise impacts in habitable rooms.

Based on the proposed classes (i.e., hard and soft conflicts), in the decision-making stage, three cases may happen: **(1)** No conflicts have been detected which results in granting the permit, **(2)** One or more soft conflicts exist that results in granting a conditional permit, and **(3)** One or more hard conflicts exist that results in a refusal to grant a permit. The conditional permit will be issued under some considerations, and it is valid as long as the conditions are respected during the construction (e.g., using special material for habitable room windows to reduce the noise impacts). Consequently, Table 4.7 specifies the final decision on issuing the permit (i.e., acceptance, refusal, and conditional acceptance) based on the classes of detected conflicts.

Table 4.7 – Making the final decision based on the class of detected 3D LuRs' conflicts

Number of Detected Hard Conflicts	Number of Detected Soft Conflicts	Final Decision
0	0	Acceptance
≥1	≥0	Refusal
0	≥1	Conditional Acceptance

4.6 Discussion and Conclusion

This chapter proposed a three-stage conceptual framework for modelling 3D LuRs, combining them with other sources of information, and detecting 3D LuRs' conflicts between modelled LuRs and physical objects for which the automation aspects was on target in all the stages. For modelling and verifying 3D LuRs automatically, the framework organised all the IFC required classes/concepts, CityGML required classes/concepts, and most importantly, the planning and zoning requirements. As an original framework, it organised and proposed mandatory principles and a generic procedure for managing/interacting with 3D LuRs leading to automating the 3D modelling and conflict detection of 3D LuRs as the main contribution of this chapter. To make the framework as generic as possible and make it independent of one or two data formats/models, the framework proposed to form 3D CityLuR outside other sources of information.

The first stage proposed the key parameters to model 3D LuRs automatically by proposing a geometric modelling approach that best fits with the key parameters. Due to incapability of LODev and LoDs to address all the information requirements to automate the process of modelling 3D LuRs and detecting their potential conflicts, two categories of level of information need have been proposed. One of which focused on combining 3D CityLuR with other sources of information including BIM design of proposed developments, 3D city models of existing buildings, and zoning maps considering the planning requirements. The second category of level of information need considers all the sources of information to automatically detect 3D LuRs' potential conflicts. As an outcome, the planning authorities will no longer be required to check all sources of information and planning documents and guidelines to determine the required information. Moreover, it is the first time that the concept of level of information is proposed for a purpose beyond BIM applications (i.e., detecting 3D LuRs' potential conflicts between modelled LuRs and physical objects). Without considering these two sets of proposed level of information need, the automatic 3D modelling and conflict detection of LuRs will fail. It showed how both geometric and semantic information are required to automatically model 3D LuR restrictions and detect their potential conflicts. Finally, this chapter discussed how the nature of detected conflicts can affect the decision-making stage. Through a discussion with planning authorities, this chapter proposed two classes of conflicts namely hard and soft conflicts with the inspiration of BIM clash classification. This classification reveals that the final decision cannot be fully automated since 3D LuRs' conflicts are sometimes subjective requiring the knowledge and expertise of planners.

Land administration and planning authorities (i.e., city councils and planning ministries) could be the main beneficiary of such a framework by having access to the LuR restricted spaces in a literally more visual way. It also helps owners/developers/ land surveyors/ architects to include all the required information in their proposed development applications to accelerate the process of verifying 3D LuR restrictions. Although this chapter focused on a specific jurisdiction (i.e., Victoria, Australia), there are many similarities in general planning rules defining LuR restrictions (e.g., building height limits and overshadowing). Therefore, the proposed framework can be applied to other jurisdictions as a source of inspiration to model and verify 3D LuR restrictions by considering differences in terms of their descriptions.

To have a fully automated process of verifying LuR restrictions, some important challenges can be highlighted as follows:

1) 3D LuR restrictions can include discretionary and mandatory rules sometimes subjective that might lead to decisions based on the knowledge and expertise of planners. This aspect reminds the importance of having qualitative reasoning in later stages.
2) 3D LuR restrictions may not only be diverse in different jurisdictions but may also be distinct in different cities. Although the general rules may be the same, it is not straightforward to achieve a generic approach that maps/represents all the limited spaces applicable in all precincts. However, as mentioned before, if the difference in the description of the rules is considered, the process (i.e., the three-stage conceptual framework) can still be the same.
3) The required data (e.g., planning information, zoning base maps, related guidelines) is provided by different organisations with different levels of accessibility. To achieve having an integrated land-use information system including all required data further studies investigating data integration aspects like data quality and standardisation are required.
4) LuR restrictions and their related information are mostly summarised in textual documents including lots of complexities that make the automation process fail. It needs further research as well as collaborative work engaging all parties to facilitate the process of modelling and verifying 3D LuR restrictions automatically.

We are working on the design and development of a planning permit assessment prototype for modelling and verifying 3D LuR restrictions automatically in which 3D spatial analyses (e.g., proximity analysis) would be utilised to detect potential LuR restriction conflicts. We believe that the modelled LuR restrictions and the specified requirement as the level of information need will contribute to detecting potential conflicts by using 3D spatial analyses tools (e.g., 3D clash detection).

Chapter 5 – A Web-Based Planning Permit Assessment Prototype: iTwin4PP

Through an experimental research project conducted with experts, this chapter is dedicated to designing and developing a web-based planning permit assessment prototype (as proof of feasibility) for automatic 3D modelling and conflict detection of 3D LuRs automatically. This chapter aims to test and evaluate the proposed conceptual framework in the previous chapter from the implementation and computational perspectives.

This chapter is the original content of the following paper.

Emamgholian, S., Pouliot, J., Shojaei, D., 2022. "A Web-based Planning Permit Assessment Prototype: iTwin4PP", Accepted to be published in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

5.1 Résumé

Le processus actuel d'émission des permis de construire repose essentiellement sur la vérification des règles d'occupation du territoire décrites via des plans d'aménagement bidimensionnels (2D) analogiques ou numériques. La vérification des géorèglementations d'utilisation du territoire en trois dimensions (3D) dans les plans d'aménagement proposés en 2D pose des problèmes aux décideurs qui doivent comprendre les limites des règlements d'utilisation du territoire et l'impact des aménagements proposés sur les bâtiments existants situés à proximité. Compte tenu de l'avancement des technologies géospatiales 3D, pour surmonter de tels défis et faciliter le processus d'émission des permis de construire, des approches numériques 3D devraient être développées pour un stockage, une analyse et une visualisation 3D efficaces des géorèglementations 3D et la détection de leurs conflits potentiels. Ce chapitre, qui s'inscrit dans le cadre d'un projet de stage avec Bentley Systems, vise à concevoir et à développer un prototype de visualisation 3D des géorèglementations basé sur le Web, appelé iTwin4PP (plateforme iTwin de Bentley). Ce prototype démontre d'abord comment les géorèglementations liées à l'approbation de la planification peuvent être modélisées automatiquement en 3D et combinées avec un environnement intégré BIM-GIS comprenant des bâtiments BIM proposés et des modèles 3D des villes. Ensuite, le prototype offre la possibilité d'effectuer des analyses spatiales 3D (en particulier des analyses de proximité) pour vérifier automatiquement les géorèglementations 3D afin de détecter les conflits spatiaux et sémantiques potentiels qui peuvent survenir entre les géorèglementations modélisées et les objets physiques/de planification. Cinq géorèglementations soumises à l'approbation par l'état de Victoria en Australie sont implémentées soit: les limites de construction en hauteur, l'exposition au soleil pour déterminer l'efficacité énergétique du bâtiment, l'ombrage dans les espaces ouverts, les impacts sonores et les limites de vue. Bien

que ces géorèglementations soient spécifiques à l'ordonnance sur les plans d'urbanisme de l'état de Victoria, nous pensons que la solution proposée peut répondre à des situations similaires d'autres juridictions.

5.2 Abstract

The current process of issuing planning permits mostly relies on checking Land-use Regulations (LuRs) against two-dimensional (2D) analogue or digital proposed development plans. Checking three-dimensional (3D) LuRs within 2D proposed development plans results in challenges for decision-makers to understand LuRs' limits and the impacts of the proposed developments on existing buildings in their surrounded proximity. Given the advancement of 3D geospatial technologies, to overcome such challenges and facilitate the process of issuing planning permits, 3D digital approaches should be developed for effective 3D storage, analysis, and visualisation of 3D LuRs and detection of their potential conflicts. This chapter, as part of an internship project with Bentley systems, aims to design and develop a web-based 3D visualisation prototype called iTwin4PP using Bentley iTwin platform. This prototype first demonstrates how 3D LuRs related to planning approval can be modelled automatically in 3D and combined with an integrated BIM-GIS environment including BIM designs of the proposed developments and GIS models of planning/city-data. Then, the prototype considers the possibility of 3D spatial analyses (especially proximity analysis) for verifying 3D LuRs automatically to detect potential spatio-semantic conflicts that may arise between modelled LuRs and physical/planning objects. Five LuRs subject to planning approval in Victorian jurisdiction, in Australia, including height limits, energy efficiency protection, overshadowing open space, noise impacts, and overlooking are highlighted. While these LuRs are specific to Melbourne's planning scheme ordinance, we believe that the prototype and encountered challenges in integrating different sources of information especially BIM and GIS, modelling 3D LuRs, and detecting their potential conflicts are common and can be applied in other jurisdictions.

5.3 Introduction

5.3.1 Context and Problematics

Mid-rise and high-rise development growth (including a combination of different types of residential and commercial buildings) especially in cities with a lack of available lands, challenges responsible authorities (e.g., city councils and planning ministry) in both statutory and strategic planning phases (Emamgholian et al., 2021a; Selmi et al., 2017). Land-use Regulations (LuRs), with their involvement in regulatory mechanisms and processes, play a significant role to restrict illegal activities and developments on lands that may not be obvious to residents (Cann, 2018; Durham Jr and Scharffs, 2019). One of such processes is issuing planning permits that currently, in many countries, is mostly two-dimensional (2D), manual, time-consuming, and subjective which might lead to decisions based on the knowledge and expertise of planners (Benner et al., 2010; Noardo et al., 2020c, 2020a; Olsson et al., 2018; Van Berlo et al., 2013). Additionally, issuing planning permits comprises diversity and multiplicity in 1) documents (e.g., documents of direct legislation like planning scheme ordinance and complementary documents like decision guidelines), 2) institutions (e.g., city councils, planning ministry, and referral authorities), and 3) sources of information (e.g., IFC, RVT, SKP, DGN, SHP, CityGML) (Guler and Yomralioglu, 2021; Noardo et al., 2020a; Plazza et al., 2019).

With advances in three-dimensional (3D) digital information technologies, especially regarding the design of proposed developments with Building Information Modelling (BIM), 3D digital approaches and prototypes can be designed and developed for effective 3D analyses and visualisation of geospatial information (Atazadeh et al., 2017; Noardo et al., 2022b; Pouliot et al., 2018, 2016; Rajabifard et al., 2019; Shojaei et al., 2018). However, required data processing and prototypes to enable modelling LuRs in 3D and consequently, detecting their potential conflicts is still lacking (Emamgholian et al., 2021a; Kitsakis et al., 2022; Kitsakis and Dimopoulou, 2017; Noardo et al., 2022a).

Enabling 3D visualisation and verification of LuRs supports decision-making tasks and mitigates misunderstandings in interpreting and checking LuRs (Barzegar et al., 2021; Emamgholian et al., 2021b, 2020a; Noardo et al., 2020b). Moreover, it is economically beneficial for both government and citizens (Grimmer, 2007). To have a better impression of the economic benefits related to the building permit process, Table 5.1 summarises the total number and value of issued building permits in 2021 in Canada based on two variables (i.e., number of permits and value of permits).

Table 5.1 – Total number and value of issued building permits in 2021 in Canada extracted from Statistics Canada[23]

Type of Building	Total No.	Value (millions of CAD)
Residential	407,841	$87,230.4
Non-residential	67,524	$39,629.9
Sum	475,365	$126,860.3

The value of permits, including materials, labour, profit, and overhead, proves how costly it can be to revoke a mistakenly issued permit during/after construction.

5.3.2 Objectives

This study is part of a research project focusing on the design and development of a three-stage conceptual framework for 1) modelling 3D LuRs geometrically, 2) combining them with 3D city models, and 3) detecting their potential conflicts based on users' needs (Emamgholian et al., in review, 2021a, 2021b, 2020a). As the

[23] https://www.statcan.gc.ca/

last phase of this research project, this study presents the outcomes of an internship project in collaboration with Bentley Systems with a focus on showcasing the feasibility of the proposed conceptual framework.

As a proof of feasibility, the general objective of this study is to design and develop a web-based planning permit assessment prototype (called iTwin4PP) for issuing planning permits automatically within Bentley iTwin platform. This prototype first demonstrates how 3D LuRs subject to planning approval can be modelled in 3D and combined with an integrated BIM-GIS environment including BIM design of the proposed developments and city-data. Then, it verifies the possibility of verifying the LuRs using 3D spatial analysis (especially proximity analysis) for detecting potential conflicts that may arise between modelled LuRs and physical objects like building elements.

5.3.3 Methodology

The methodology of this research follows an engineering type of approach to design and develop a web-based planning permit assessment prototype for issuing planning permits automatically. This prototype is developed by coding within the iTwin platform using JavaScript and ReactJS to address specific requirements as follows:

- Loading different data sources (e.g., zoning base map and BIM design of a high-rise building as a proposed building in IFC format or RVT) into iTwin,
- Modelling and visualising selected 3D LuRs geometrically,
- Combining the LuRs with the proposed and adjoining buildings,
- Verifying the LuRs by a set of analytical rules based on required geometric and semantic information,
- Detecting and locating the potential conflicts among LuRs and physical objects like building elements, and
- Visualising the conflicts (e.g., a complete report of validation checks).

The feasibility of the prototype is assessed based on a specific use-case of issuing planning permits in the city of Melbourne in Victoria, Australia, as a case study. The tests are performed on a high-rise building by assessing five specific regulations including height limits, energy efficiency protection, overshadowing open space, noise impacts, and overlooking. The next section reviews the iTwin functionalities underlying this study. Section 5.5 summarises the procedures for two developed functionalities focusing on modelling and verifying the 3D LuRs automatically that will be followed by a showcase of the tests were performed and the evaluation (section 5.6). Finally, the conclusions derived through this study are addressed by discussing issues that require further research (section 5.7).

5.4 Reviewing iTwin Functionalities Underlying This Study

Bentley's iTwin platform[24], as a starter kit for developing web applications for infrastructure digital twins, enables the integration of heterogeneous 3D geospatial information. This section briefly reviews the iTwin components prior to presenting the developed planning permit assessment prototype. It should be noted this section only covers the components underlying this study including iModel, Base Infrastructure Schema (BIS), iModel console, iTwin Synchroniser, iTwin viewer, and iTwin clash detection API.

- iModel: An iModel is a cloud-ready format for all the datasets that need to be added to the iTwin platform. Via several built-in iModel connectors[25] (e.g., GIS, IFC, and MicroStation connectors) different file formats can be converted to the cloud-ready format in iModelHub which keeps the track of datasets and any changes within the iTwin platform.
- Base Infrastructure Schema (BIS): BIS[26] defines a set of base classes (e.g., 3D geometry) for capturing the core commonality of all the datasets with different formats as well as a set of specialised classes (e.g., descriptions and labels). It utilises a hierarchical structure containing different schemas in which there are several classes for which there are various properties. BIS enables the users to write queries for different/disparate data sources.
- iModel console: iModel console is another component of the iTwin platform that will be used to write queries within iModel. The queries should be in ECSQL[27] language which is based on SQL. As an example, all elements in BIS have a unique identifier ID (i.e., ECInstanceId) than can be retrieved within queries in the iModel console.
- iTwin Synchroniser: Synchronisation aims to translate and aggregate different data formats (e.g., Revit, IFC, DGN, SHP) into an aggregated dataset using iTwin synchroniser[28]. Via iTwin synchroniser, the iModel connectors can be enabled for aggregating all the required data formats. It should be noted that synchronisation should not be confused with the data federation concept which is used for connecting data from external sources such as JSON and databases.
- iTwin viewer: An iTwin viewer[29] is an open-source application written in TypeScript for being connected to the iTwin platform for visualising the datasets. It handles authentication process and contains different built-in functionalities like zoom and rotation as well as user interface tools such as decorators, markers, colorise, and show/hide tools.
- Clash detection API: iTwin contains several APIs like clash detection API[30] that mainly focuses on finding those physical objects/elements colliding or coming under clearance limits geometrically with other physical objects/elements in the digital twin application. As an example, it can be used for finding soft/hard clashes in BIMs.

[24] https://www.itwinjs.org/
[25] https://www.itwinjs.org/learning/imodel-connectors/
[26] https://www.itwinjs.org/bis/
[27] https://www.itwinjs.org/learning/ecsqltutorial/
[28] https://www.bentley.com/en/resources/itwin-synchronizer
[29] https://developer.bentley.com/apis/visualization/
[30] https://developer.bentley.com/apis/clash-detection/

Besides being open source, the main reason for selecting the iTwin platform is that it allows the integration of a variety of common 3D formats like IFC and RVT as a common format that many architects are working with to design proposed developments. It should be noted that the IFC/Revit connector can read/store the building geometries/semantics required for automating the process of issuing planning permits. In addition to its visualisation functionalities for BIM and GIS data, it enables writing different spatio-semantic queries. However, it does not include a CityGML connector for integrating the CityGML data format.

5.5 Planning Permit Assessment Prototype - iTwin4PP

The planning permit assessment prototype, called iTwin4PP, is a web-based prototype that was designed and developed in this research project for issuing planning permits using Bentley iTwin platform. The iTwin4PP consists of different developed tools to facilitate the process of issuing planning permits. Two main capabilities are developed focusing on modelling first LuRs in 3D and second verifying 3D LuRs to detect potential conflicts between modelled LuRs and physical (e.g., building elements) or planning (e.g., public open spaces) objects.

5.5.1 iTwin4PP - Modelling Procedure

The iTwin4PP, as proof of feasibility, focuses on five specific LuRs subject to planning approval in Victorian jurisdiction including height limits, energy efficiency protection, overshadowing open space, noise impacts, and overlooking. The selection is in a way that proves the applicability of the prototype for modelling LuRs by utilising different geometric modelling approaches such as extrusion (for height limits), sweeping (for noise impacts), Boundary Representation (B-Rep) (for overshadowing), and Constructive Solid Geometry (CSG) by the union of a quadrant and a cube plus extrusion (for overlooking). To model the LuRs automatically (called 3D CityLuR), the prototype utilises the modelling parameters identified and proposed by Emamgholian et al. (in review, 2021a).

- **Height limits:** This LuR focuses on checking the proposed development regarding the maximum allowed height. For modelling this LuR, iTwing4PP first, makes a query in the BIS by using iModel console to retrieve the centre coordinates of the proposed development. Second, it creates a rectangle with a predefined length and width surrounding the proposed building. Then, by considering the maximum allowed height in the zone where the proposed development is located and using a linear extrusion approach, it geometrically models the height limits (Figure 5.1)

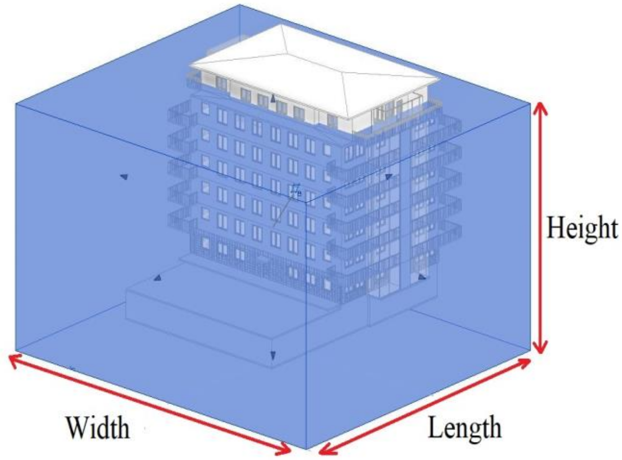


Figure 5.1 – Height limits modelled by using linear extrusion.

- **Energy efficiency protection and overshadowing open space:** For both LuRs, a volumetric shadow is required. The prototype utilises the reverse engineering method proposed by Emamgholian et al. (2021a) to model the volumetric shadow using B-Rep (Figure 5.2). The iTwin4PP first gets the 2D shadow corner points on the terrain or shadow points with a pre-defined threshold in more complex shadows (i.e., blue multiplication signs in Figure 5.2). Second, it reads the centre coordinates of the proposed development and calculates the distance (Di) between each shadow point and the centre coordinates of the proposed development. Third, by defining the Di as the sweeping distance, it sweeps the shadow points on the terrain along the sun direction (α) to obtain the top points approximately (i.e., red multiplication signs in Figure 5.2). Then, by creating points with the zero height (or the first-floor height) for the obtained top points, corresponding points on the terrain are created. Finally, by having access to all points the energy efficiency protection and overshadowing open space LuRs are modelled using the B-Rep approach.

  It should be noted that the extraction of 2D shadow points on the terrain is not part of this prototype. In addition, the proposed approach for obtaining top shadow points might overlap/cause a gap with the proposed development. But since here the proposed development should be checked with surrounding buildings and open spaces, it meets users' requirements in the process of issuing planning permit. Moreover, it facilitates the modelling phase extensively since there is no need to extract the proposed developments' geometries to obtain the top shadow points.

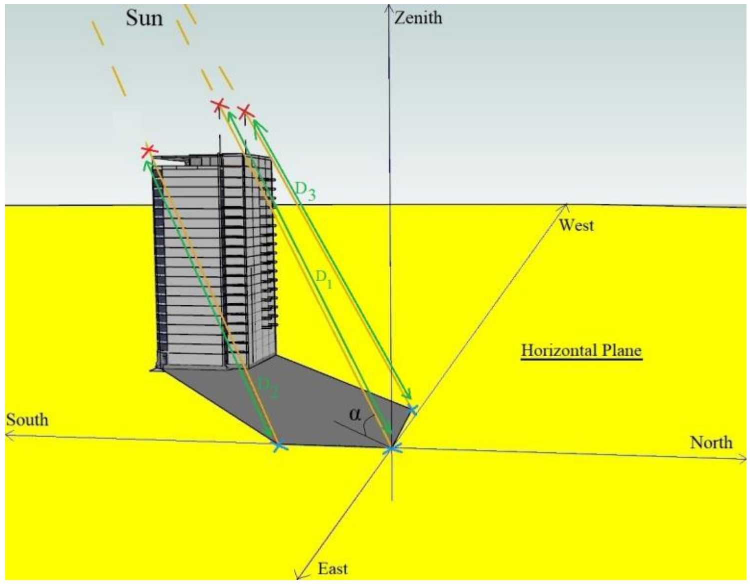


Figure 5.2 – Energy efficiency protection and overshadowing open space points extraction in order to model it using B-Rep (adapted from Emamgholian et al. (2021a)).

- **Noise impacts:** This LuR checks the proposed developments' habitable room windows against roads, railway lines, and industry points closer than a specified distance (e.g., 300 meters for freeways carrying 40,000 Annual Average Daily Traffic Volume). The iTwin4PP first gets the roads/railway lines' width and centre points coordinates. Second, it creates a semi-circle with the specified radius based on the planning scheme and guidelines. Finally, to model the noise impacts geometrically, the semi-circle is swept along the road path. It should be noted that since the road direction might change, both translation and rotation of the semi-circle along the Z-axis (Rz) based on the road's direction at every two points are considered (Figure 5.3).

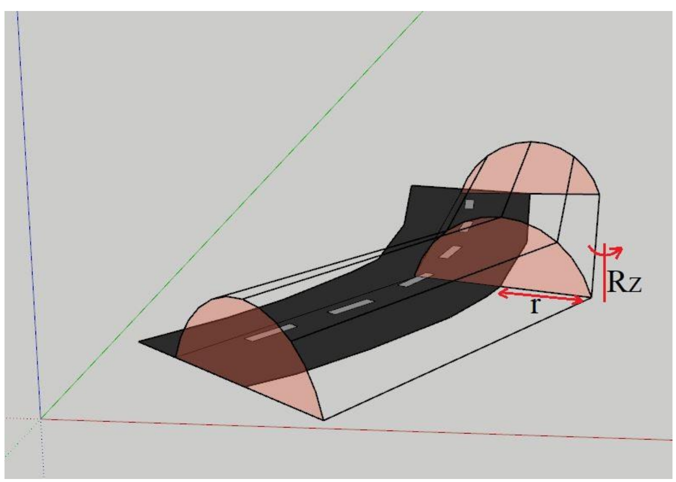


Figure 5.3 – Noise impacts modelled by using sweeping approach.

- **Overlooking:** This LuR checks the direct line of sight of the proposed developments' habitable room window, balcony, terrace, and deck or patio into existing buildings' habitable room windows and secluded private open spaces. The iTwin4PP only focuses on habitable room windows. But the process is almost the same for other building entities such as the balcony, terrace, and deck or patio.

To model the overlooking LuR, the prototype first retrieves the proposed development's habitable room windows coordinates and width by querying the iModel datasets with the BIS schema using the iModel console. Second, based on the window width, forms the union of a triangle (coloured in red in Figure 5.4) and arc (coloured in yellow in Figure 5.4) by using the union operator of the CSG modelling approach. Third, the iTwin4PP translates and rotates the unionised form along the Z-axis based on the location and true north angle of the proposed building's windows that are retrieved from the iModel. Finally, by extruding the unionised form to 1.7 meters from the window's floor level (based on Melbourne's planning scheme and guidelines), the overlooking can be modelled geometrically as illustrated in Figure 5.4.

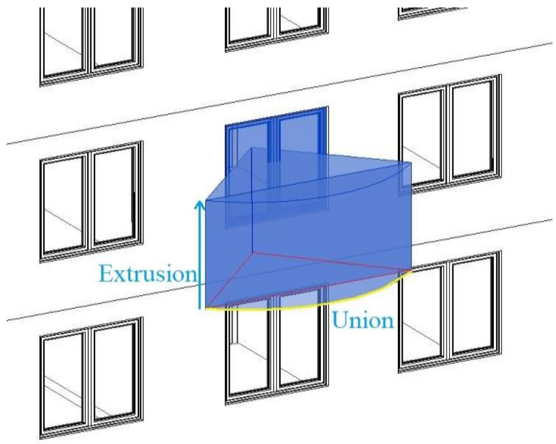


Figure 5.4 – Overlooking modelled by using CSG and extrusion modelling approaches.

5.5.2 iTwin4PP - Clash Detection Procedure

This phase focuses on verifying 3D LuRs automatically using clash detection API by defining a set of geometric and semantic rules inside the iTwin4PP's iModel. The clash detection API needs two sets of model/category IDs referring to elements that are needed to be checked regarding collision. It can be a model (e.g., the proposed building) or a category (e.g., walls/windows) ID. This enables the prototype to detect spatio-semantic conflicts between modelled LuRs and physical/planning objects like building elements/public open spaces.

For example, Figure 5.5 shows the defined rules structure/components for detecting height limit conflicts. While the values might change for different LuRs, the procedure is the same for all other LuRs. For defining height limit conflict detection rule, the proposed building is the first element and the modelled height limits should be set as the second element. The defined rules include:

- ModelIds and categoryIds: All models and categories have a unique ID that can be retrieved by querying the iModel. Category IDs should be specified whenever specific building elements (e.g., windows) need to be checked.
- selfCheck: When selfCheck is false, the clashes will only be checked against elements in the opposing set.
- Clearance: When clearance is set above 0, any elements within this distance will be reported as a clash.
- SuppressTouching and touchingTolerance: When suppress touching is true, the results will not include elements that are touching, or whose clash overlap falls within the touching tolerance limits.
- IncludeSubModels: When it is true, any sub-models under the specified model will be included.

```
"test": {
    "id": "(iModel ID)",
    "displayName": "Height Conflicts",
    "description": "Detecting Height Conflicts",
    "setA": {
        "modelIds": ["(Proposed Building's ID)"],
        "categoryIds": [],
        "selfCheck": false,
        "clearance": 0
    },
    "setB": {
        "modelIds": ["(Modelled Height Limits)"],
        "categoryIds": [],
        "selfCheck": false,
        "clearance": 99mm
    },
    "suppressTouching": false,
    "touchingTolerance": 0,
    "includeSubModels": false,
    "suppressionRules": [],
}
```

Figure 5.5 – Defined rule for detecting height limit conflicts.

5.6 Results and Evaluation

The iTwin4PP loads the BIM file and models the selected LuRs (i.e., height limits, energy efficiency protection, overshadowing open space, noise impacts, and overlooking) automatically. Then, it detects and locates the LuRs' potential conflicts automatically by the defined geometric-semantics rules using the iTwin clash detection API.

The tests were performed on a complex BIM design in RVT format. Via iTwin synchroniser, planning scheme zones[31] and overlays[32] related to Fishermans Bend area in the city of Melbourne are added to the iModel in SHP format (coloured blue in Figure 5.6). Planning scheme zones/overlays are required to retrieve the zone and the assigned LuRs' restrictions where the proposed building is located. In addition, the digital terrain model, Bing Maps with labels, and OSM buildings of existing buildings are added to the iTwin viewer. To enhance the

[31] https://discover.data.vic.gov.au/dataset/planning-scheme-zones-vicmap-planning
[32] https://discover.data.vic.gov.au/dataset/planning-scheme-overlay-vicmap-planning

visualisation aspects, for all the datasets a show/hide toggle button is added to the viewer as illustrated in Figure 5.6.

Figure 5.6 – Added datasets in iTwin4PP.

The prototype is developed by coding based on JavaScript and ReactJS using the iTwin library[33] in Visual Studio Code. It should be noted that the planning authorities (e.g., councils and planning ministry) are the target users of this prototype.

5.6.1 Modelling LuRs in 3D

Figure 5.7 illustrates the modelling control tools in the iTwin4PP. For height limits, an option for selecting the planning zones/overlays with an initial height limits value (if any) is added. In addition, as the height limit LuR might not be the same for the entire zone/overlay, it can also be changed interactively. For overshadowing LuRs, since it should be checked in specific dates (e.g., 22nd of September) and times (e.g., 11:00 or 13:00), the prototype includes an option for changing the date and time to retrieve the required sun direction and 2D shadow on the terrain.

[33] https://www.itwinjs.org/learning/

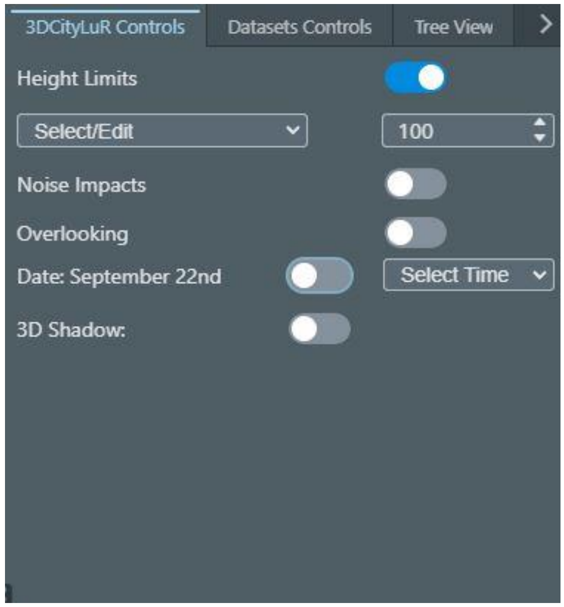


Figure 5.7 – Modelling control tools in iTwin4PP.

Figure 5.8 shows the results of the modelled height limits, noise impacts, and overshadowing LuRs. The noise impacts LuR is modelled for part of Lorimer St and the overshadowing is modelled considering four specific times (i.e., 11:00, 12:00, 13:00, 14:00) of the 22nd of September considering the Melbourne planning scheme ordinance. For modelling noise impacts, centre line coordinates of the highway and for overshadowing, the 2D shadow coordinates were retrieved from a JSON file. While the modelling procedure is automatic, some tools still need to be developed to extract the required geometries (i.e., roads/railway lines' centre points or 2D shadows on the terrain).

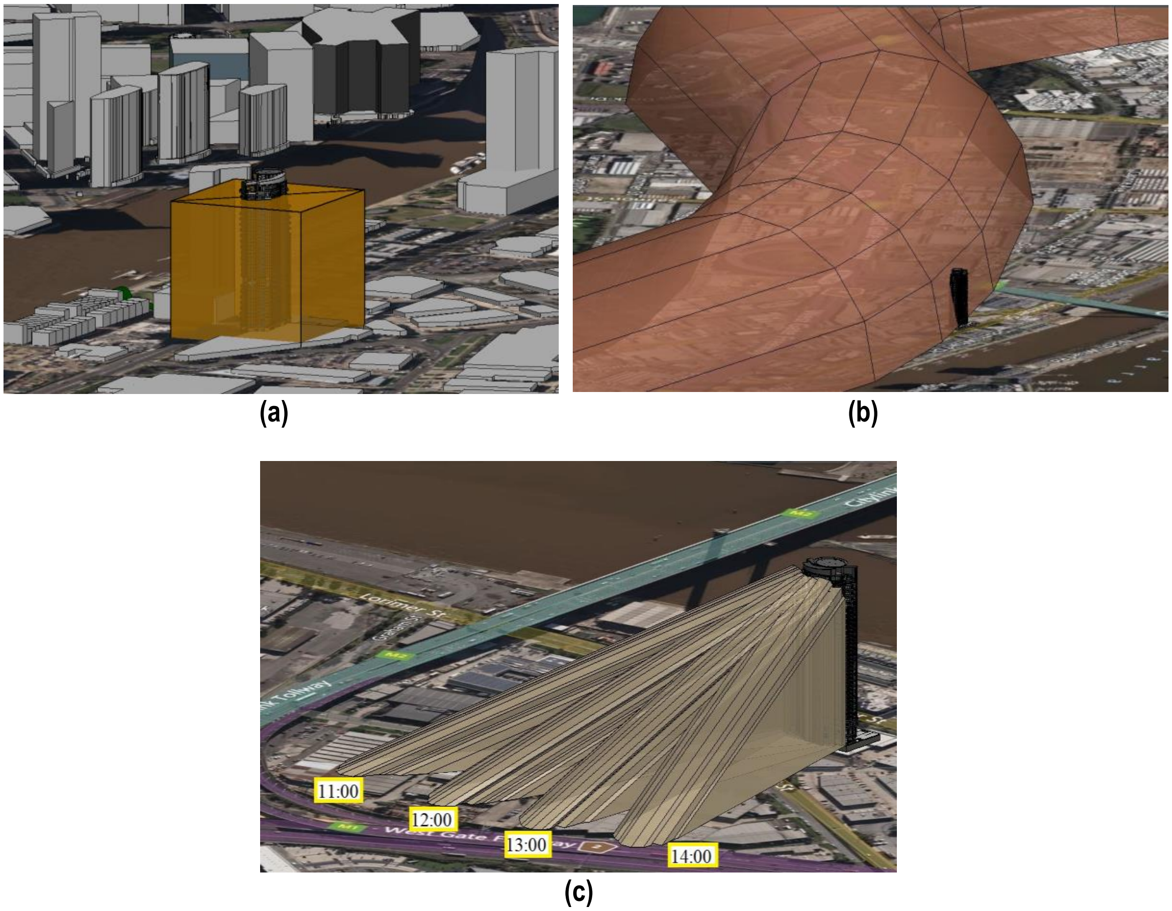


Figure 5.8 – Modelled LuRs; **a)** height limits, **b)** noise impacts, and **c)** volumetric shadow in four specified times.

Overlooking regulation was modelled for different windows of the proposed development with varied widths and true north angles to show the applicability of the prototype for any habitable room windows in the proposed building (Figure 5.9). It should be noted that the windows' floor height, width, and true north angles were retrieved automatically by querying the iModel. Figure 5.9 illustrates the modelled overlooking LuR for three windows with different properties.

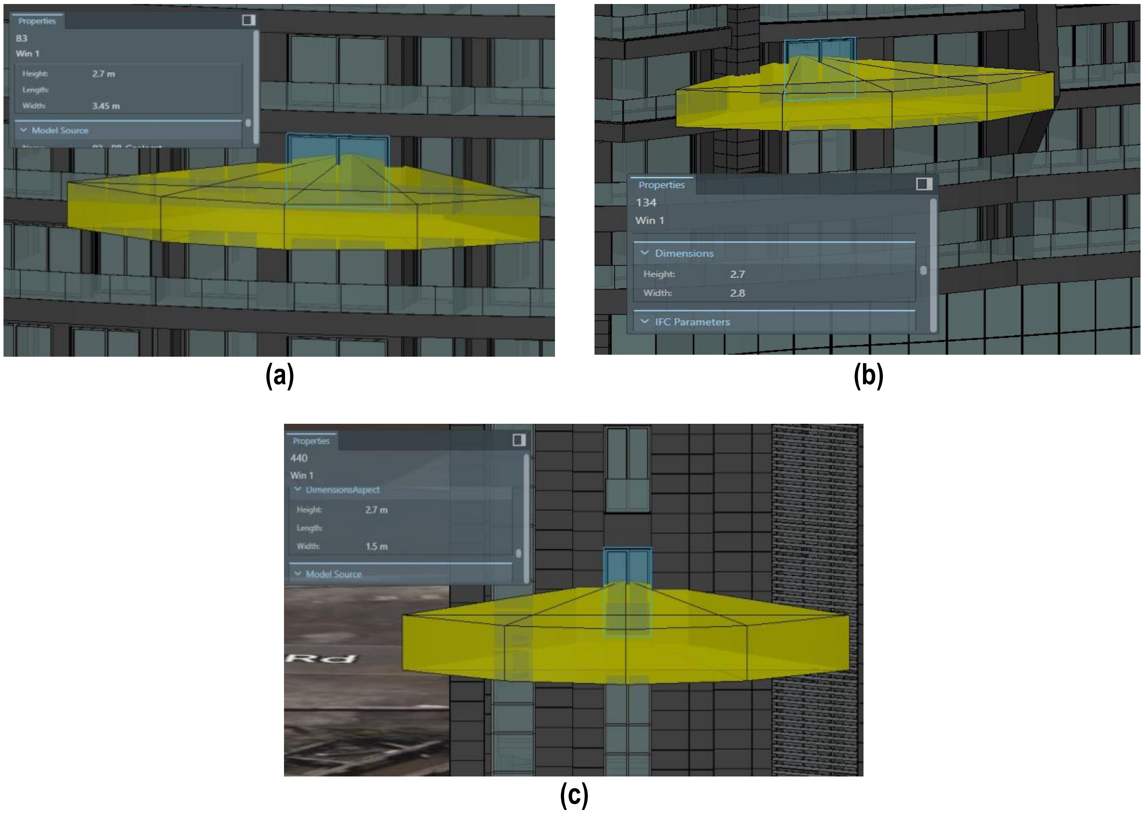
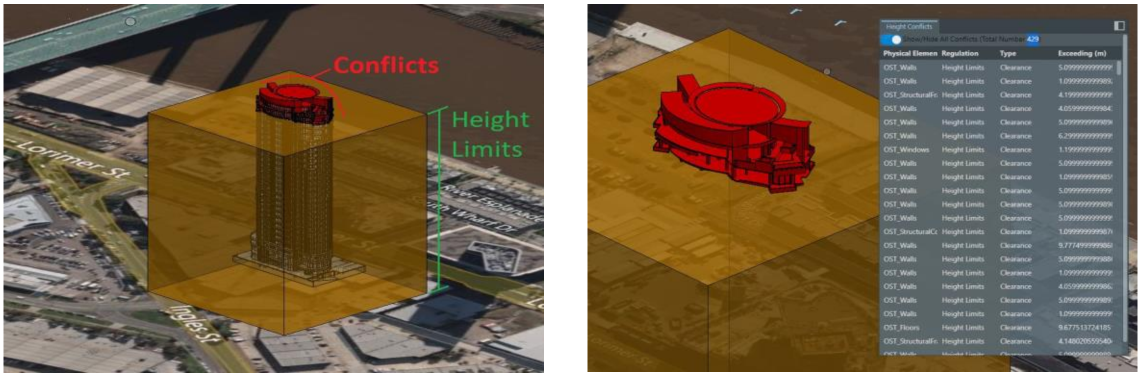


Figure 5.9 – Modelled overlooking LuR for a window with a width of **a)** 3.45 meters, **b)** 2.8 meters, and **c)** 1.5 meters.

5.6.2 Detecting 3D LuR conflicts

In this stage, potential conflicts between the modelled LuRs and planning/physical objects are detected by taking the advantage of the iTwin clash detection API and defining analytical rules (e.g., based on proximity analysis) by considering both required geometric/semantic information. The clash detection API needs two sets of elements for each test.

- **Height limit conflicts:** For detecting height limit conflicts the proposed development should be set as one of the elements that should be checked against modelled height limits LuR as another element. In this case, since the building elements that are not geometrically colliding with the modelled height limits matter, the prototype considers a clearance vertical distance (i.e., 1 cm) to detect those buildings' elements that are above the height limit (see Figure 5.5). This clarifies that the detected elements are not respecting the height limits LuR. It should be noted that the defined rule here only needs to consider the geometric characteristics of the conflict. Figure 5.10 (a) shows the detected height conflicts of the proposed building that can also get filtered and reported as illustrated in Figure 5.10 (b). In addition, the maximum vertical exceeding distance (i.e., ~10 meters) can be identified by checking the exceeding tab in the results. Finally, the conflicts can be grouped or filtered individually by clicking on the table.



(a) **(b)**

Figure 5.10 – Detected height limits conflicts (coloured in red) with **a)** a full view and **b)** a zoomed view in which the conflicts got filtered.

- **Energy efficiency protection and overshadowing open space:** For detecting overshadowing conflicts, the public open spaces in planning scheme zones/overlays play as one of the elements, and the modelled overshadowing in specified times/dates is the other element in the clash detection API. Public open spaces IDs can be retrieved by querying the iModel regarding the planning scheme zones/overlays category IDs. The iTwin4PP only checks these LuRs against surrounding public open spaces. However, by having access to the 3D city model with a sufficient level of information, private open spaces and roof-top solar energy panels of the surrounding buildings can also be verified against the modelled overshadowing LuR. Figure 5.11 illustrates the detected overshadowing conflicts against surrounding public open spaces (coloured in red).

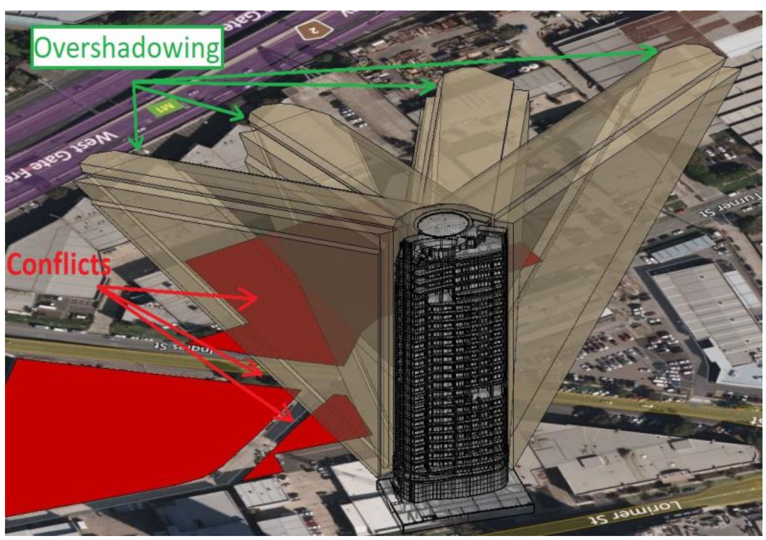
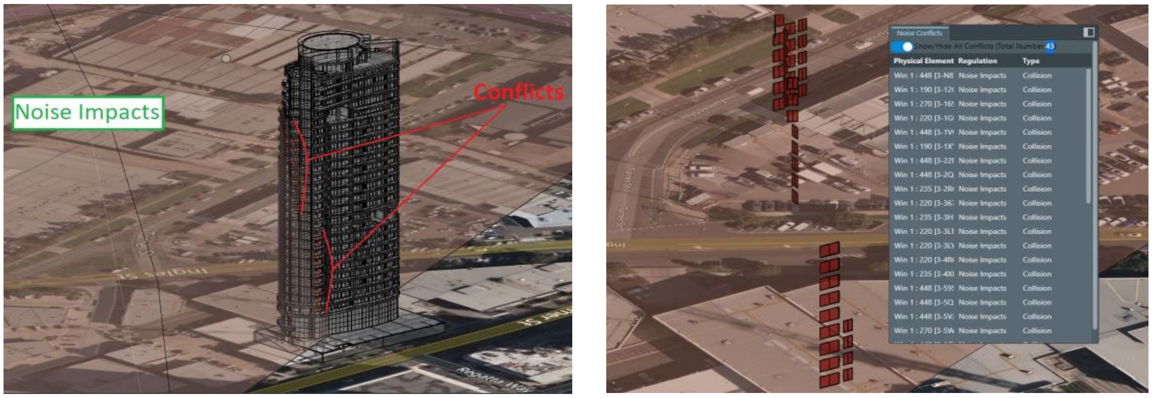


Figure 5.11 – Detected overshadowing conflicts against public open spaces for the four specified times.

- **Noise impacts:** For detecting noise impacts conflicts, the habitable room windows in the proposed development are set as the first element and the modelled noise impacts LuR as the other element. Habitable room windows IDs are retrieved automatically from the iModel by querying the proposed development's models and categories. The habitable room windows were defined in the BIM design manually using Revit. Since the habitable room windows are the target elements, here a geometric rule cannot guarantee the conflicts can be detected properly and both geometric and semantic aspects should be considered in the defined rule. Figure 5.12 (a) shows the detected noise impacts conflicts that can also get filtered and reported as presented in Figure 5.12 (b).



(a) **(b)**

Figure 5.12 – Detected noise impacts conflicts (coloured in red) with **a)** a full view and **b)** a zoomed view in which the conflicts got filtered.

- **Overlooking:** Since the iTwin4PP does not include surrounding buildings with a sufficient level of information (i.e., existing buildings including habitable room windows and private open spaces), in this stage, the modelled overlooking LuR could not be verified to see if the conflicts exist. However, as mentioned before, by having access to surrounding buildings with the required information, it can be automatically verified.

In the last stage, to check and evaluate the performance of the prototype as an internal validation process, the results of the detected conflicts (Table 5.2) were compared in a manual manner by exploring the 3D model visually. For height limits, all 429 building elements above the modelled height limit LuR were detected. For height limit conflicts, the vertical exceeding distance also matters that can be identified from the reported conflicts (Figure 5.10 (b)). For verifying overshadowing LuR, 7 conflicts between the modelled LuR and public open spaces were detected as expected. Finally, 43 habitable room windows were detected as noise impacts LuR conflicts for which special material should be considered during the construction to mitigate noise impacts in habitable rooms. The results proves that the developed prototype, as a proof of feasibility, can be utilised to facilitate the decision-making process for the responsible authorities (e.g., councils and planning ministry).

Table 5.2 – Evaluation results specifying the number of conflicts that were expected to be detected.

LuR	No. of Conflicts	Detected by iTwin4PP
Height Limits	429	429
Overshadowing Open Space	7	7
Noise impacts	43	43

5.7 Conclusion and Future Steps

This chapter presented an original web-based planning permit assessment prototype, called iTwin4PP, for issuing planning permits by using the iTwin open-source platform with the potential for future developments. To our knowledge, this is the first web-based prototype enabling the automation of modelling LuRs in 3D and verifying them to detect the potential conflicts in issuing planning permits. In our opinion, this work opens the door to new market and technology development applied to land administration and land planning domains.

iTwin4PP and the underlying procedure show a number of advantages. First it enables the 3D visualisation of LuRs and consequently improves the understanding of their horizontal but mostly vertical extents. Moreover, it allows detecting potential conflicts between 3D LuRs and existing/proposed buildings. Our development reveals how 3D spatial analyses, as well as both geometric and semantic checks, jointly are necessary to detect the arisen conflicts automatically.

Planning authorities (e.g., councils and planning ministry) can be the main beneficiary of the prototype and procedures. The manual process of evaluating the results showed that the conflicts are detected correctly, and the developed prototype, as a proof of feasibility, can be utilised for the early decision-making process for issuing planning permits.

However, although we have received positive feedback on the developed prototype from DELWP[34], for now, this prototype is not fully validated nor confronted with a concrete decision-making process, and this is part of upcoming work. In addition, this research showed that for having a fully automated process, how important can be having access to the 3D city model containing existing buildings including required geometries and semantics (e.g., habitable room windows or private open spaces). Since most cities can have such challenges, AI capabilities to extract the required information from existing buildings can be a solution to overcome this issue.

While the selected LuRs are specific to Melbourne's planning scheme ordinance, we believe that the developed prototype and encountered challenges (e.g., integrating different sources of information, modelling/verifying 3D LuRs) are common among different jurisdictions and can be utilised as a source of inspiration for similar research studies and projects.

[34] DELWP is the responsible authority for assessing development applications containing a total gross floor area of more than 25,000 square metres in the state of Victoria

Conclusions and Perspectives

Back to the Research Objectives

The general objective of this research was **to design a conceptual framework based on planning authorities' needs that formalises required geometric and semantic information in different sources of 3D spatial information (e.g., BIM, city models, and planning maps/information) for modelling LuRs in 3D and detecting LuRs' potential spatio-semantic conflicts**. Chapter 4 proposed a three-stage conceptual framework for (1) modelling 3D LuRs automatically (called 3D CityLuR) by specifying LuRs' key parameters and a geometric modelling approach that best fits with the identified key parameters, (2) combining 3D CityLuR with other sources on information like BIM, 3D city models, and 3D zoning, and (3) verifying 3D LuRs to detect potential spatio-semantic conflicts automatically. For modelling and verifying 3D LuRs automatically, the framework organises all the IFC required classes/concepts, CityGML required classes/concepts, and most importantly, the planning and zoning requirements. As the main outcome, this framework fills the gap regarding the lack of a concrete organisation of principles and procedures to automatically model 3D LuRs and detect their potential conflicts. As another outcome, the planning authorities will no longer be required to check all sources of information and planning documents and guidelines to determine the required information. It should be highlighted that the framework forms 3D CityLuR outside the model and then combines it with other sources of information. This makes the proposed framework a generic approach in which 3D CityLuR is independent of CityGML or IFC and it can be integrated with any other kind of data.

Five specific objectives have been defined, which are discussed in detail in the following.

1) To formulate an inventory of various 3D LuRs specifying their 3D/vertical components.
2) To propose a functional classification based on the magnitude of 3D LuRs' potential conflicts for supporting planning authorities' decision-making goals.

As discussed in Chapter 1, exploring LuRs to understand their 3D/vertical aspects was an important step leading to understanding incoherence in the 3D visualisation of LuRs using traditional 2D mapping systems. Since there were no inventory or organisation of LuRs with 3D components, Chapter 1 first explored the LuRs comprising 3D components and then, proposed an inventory of LuRs by highlighting their 3D components. To achieve the first objective, in total, after reviewing more than **a hundred** 2D/3D LuRs, **eighteen** 3D LuRs are discussed and their 3D components are highlighted including **1)** site coverage, **2)** walls and carports on boundaries, **3)** car parking spaces, **4)** projections beyond street alignment, **5)** buildings separation, **6)** depth limitation, **7)** height Limits, **8)** side and rear setbacks, **9)** street setbacks, **10)** north-facing windows, **11)** energy efficiency protection, **12)** overshadowing open space, **13)** solar access to open space, **14)** daylight to existing windows, **15)** daylight to new windows, **16)** overlooking, **17)** noise impacts, and **18)** flooding limits.

To achieve the second objective, after exploring 3D LuRs, Chapter 1 also proposes five variables including the number of LuRs and physical objects involved in the conflicts, LoD of the proposed development and surrounding buildings, and 3D spatial configuration of LuRs referring to the shapes that are used to represent LuRs in 3D. Then, two classes of conflicts' magnitude (i.e., hard and soft conflicts) have been proposed by considering the conflicts' magnitude in the data processing and their impacts on the decision-making process. The main value of this classification is to extend our understanding of 3D LuRs and to support decision-makers in the detection of spatio-semantic conflicts between physical objects and LuRs. For example, based on this classification, height limit conflicts have been classified as soft and overshadowing and overlooking conflicts as hard conflicts which highlight the simplicity of detecting height limit conflicts compared to the overshadowing or overlooking conflicts. In addition to highlighting the importance of the 3D spatial configuration of LuRs, this phase highlighted the incapability of LoD concept to model and verify 3D LuRs automatically which forced me to think about a new concept as level of information need. Finally, through a discussion with planning authorities at DELWP, the discretionary and mandatory aspects of LuRs' conflicts have been selected as the main variable to classify the conflicts in chapter 4.

3) To model LuRs in 3D automatically and then combine them with other sources of information (e.g., BIM, city models, and zoning maps) to support automatic conflict detection in planning approval and building subdivision processes.

In chapters 2, 3, and 4, we addressed identifying 3D modelling key parameters and subsequently, utilising geometric modelling approaches to model 3D LuRs automatically and combining them with other sources of information (e.g., BIM, city models, and 3D zoning). To achieve this objective, this thesis investigated how 3D LuRs can be modelled in 3D and then combined with other sources of information (e.g., BIM, city models, and zoning maps). For the first time, this thesis has investigated all possible ways for modelling LuRs comprising 3D components. To model 3D LuRs, key modelling parameters have been extracted from legal textual information for **twelve** 3D LuRs subject to planning approval including **1)** height Limits, **2)** side and rear setbacks, **3)** street setbacks, **4)** north-facing windows, **5)** energy efficiency protection, **6)** overshadowing open space, **7)** solar access to open space, **8)** daylight to existing windows, **9)** daylight to new windows, **10)** overlooking, **11)** noise impacts, and **12)** flooding limits. Next, to make the automatic instantiation of 3D LuRs possible, this thesis tried to find a way to automatically model 3D LuRs using 3D geometric modelling approaches. Accordingly, a geometric modelling approach that best fits those parameters has been proposed to automatically model these LuRs. Then, 3D CityLuR (as a 3D model for representing LuRs' legal extents on a city scale) has been formed automatically by instantiating 3D LuRs extents automatically.

Specific attention has been carried out to forming 3D CityLuR independent of one format or modelling approach so that in a later stage, it can be combined with other sources of information (e.g., BIM, city models, and 3D zoning). The first reason to do so is that generally IFC and CityGML are formed for supporting physical objects like building elements. They use LODev and LoD to show the complexity of 3D models in different aspects such as geometries and semantics that do not incorporate the concept of LuRs. Therefore, for forming 3D CityLuR we need both proposed development and existing buildings as well as planning and zoning information. As another reason to do so, 3D CityLuR requires using multiple geometric modelling approaches on a city scale which makes it nearly impossible to model them within 3D city models like CityGML which uses B-Rep, or BIM which is a suitable geo-context for representing one or a limited number of buildings. The last but not least, there is no need to store and keep modelled LuRs for the long term since after detecting LuRs' conflicts, they are not required anymore. This makes 3D CityLuR independent of one or two data models and it can be combined with any format of 3D models.

To combine 3D CityLuR with other sources of information automatically, the level of information need covering both required planning information and BIM/CityGML requirements in terms of geometries and semantics, as well as the required LODev/LoDs in proposed/existing buildings, have been proposed. Without this stage, 3D CityLuR cannot be combined with other sources of information automatically. As a proof of concept, it has been also showcased to model and combine 3D LuRs (as 3D CityLuR) utilising different geometric approaches within a BIM-GIS integrated model (Chapter 2). 3D CityLuR is a foundation for the later stage which aims to detect potential conflicts between modelled LuRs and physical objects to have a digital planning permit.

4) To identify the level of information need (i.e., geometries and semantics) for automatically detecting LuRs' potential spatio-semantic conflicts that might arise between the modelled LuRs and physical objects.

To achieve this objective, this thesis first highlighted the shortcomings of LODev in BIM and LoDs in 3D city models (chapters 2 & 4) in specifying information requirements for modelling LuRs in 3D and detecting their potential spatio-semantic conflicts. Taking overlooking LuR as an example, the windows of habitable rooms in proposed developments must not provide a direct line of sight to existing habitable room windows or private open spaces. In this case, the required Level of Detail (LoD) in 3D city models or Level of Development (LODev) in BIMs, cannot fully guarantee that the modelling or compliance checking of overlooking LuR can be conducted without needing further information. Because the city data or BIM design might not distinguish habitable room windows from other windows. Also, sometimes planning information like zoning map restrictions might be needed that is related to neither CityGML LoDs nor BIM LODev.

Second, this thesis focused on formalising required information (as the level of information need) in different sources of 3D spatial information (e.g., BIM, city models, and planning maps/information), this time for detecting 3D LuRs' spatio-semantic conflicts automatically (chapter 4) by considering both geometries and semantics (i.e., class of object and attributes). This should not be confused with the first category of level of information need which was related to the automatic combination of 3D CityLuR with other sources of information. This proposed level of information need covers the information requirements for detecting the formerly **twelve** modelled 3D LuRs' conflicts i.e., **1)** height Limits, **2)** side and rear setbacks, **3)** street setbacks, **4)** north-facing windows, **5)** energy efficiency protection, **6)** overshadowing open space, **7)** solar access to open space, **8)** daylight to existing windows, **9)** daylight to new windows, **10)** overlooking, **11)** noise impacts, and **12)** flooding limits. In this stage, the level of information need specifies the minimum data requirements to automate the process of verifying 3D LuRs to detect LuRs' potential spatio-semantic conflicts (that might arise between the modelled LuRs and physical objects like building elements). It also makes the decision-making process faster since planning authorities do not need to identify the required information from planning maps and documents and check them in 3D models to make sure all the required information is included.

5) To design and develop a web-based planning permit assessment prototype (as proof of feasibility) for modelling and verifying 3D LuRs automatically in the process of issuing planning permits.

In chapter 5, as proof of feasibility, the proposed three-stage conceptual framework has been validated via the design and development of a web-based planning permit assessment prototype to model LuRs in 3D and detect their potential conflicts automatically. The prototype after getting the BIM design, first, models LuRs in 3D automatically by retrieving the required information from different sources of data (e.g., proposed building and zoning map). Then, it detects and locates the LuRs' potential conflicts automatically by the defined geometric-semantics rules using the iTwin clash detection API. To test and evaluate the performance of the prototype, five LuRs have been selected including: **1)** height limits, **2)** energy efficiency protection, **3)** overshadowing open space, **4)** noise impacts, and **5)** overlooking. Via an internal validation process, the results showed that all the conflicts were detected correctly. As the main outcome, this prototype validated the feasibility of the proposed conceptual framework in enabling the automation of modelling the selected LuRs in 3D and verifying them to detect the potential spatio-semantic conflicts automatically. This has been achieved by retrieving the identified required information as the level of information need (i.e., both geometrics and semantics) from the BIM design and planning maps. Eventually, it highlighted how important it could be to have access to a city-scale dataset including the identified required information in existing buildings and city furniture. However, although we received positive feedback on the prototype and the way it works, due to the lack of data and data privacy policy we could not test the prototype for a real proposed development at this stage.

It should be noted that since the start of this Ph.D. research, there was close contact with DELWP as the responsible authority for statutory planning in Victoria. Through several virtual online meetings, the usability of different stages of this Ph.D. research has been tested and evaluated with experts at DELWP. A manager of Visualisation & Special Projects in Planning Information Services, a Senior Planner in Development Approvals and Design were the regular attendants, and a Project Officer in Visualisation, a Senior Manager of Architecture and Data Capability, and a Manager in Development Approvals and Design were other attendants of these meetings in different phases of this Ph.D. research. As the main outcome, these meetings helped to align the thesis direction with the responsible authorities' requirements and test and evaluate the usability of this research.

Back to the Research Hypotheses

To answer the first research question, i.e., "**does the geometric 3D modelling of LuRs enable the automation of LuRs' verification process to detect potential LuR conflicts for supporting planning authorities' decision-making goals?**", this thesis hypothesised:

It is possible to fully automate (a) 3D geometric modelling of all LuRs comprising 3D components and (b) detection of all potential LuRs' conflicts for issuing planning permits.

To test the validity of this hypothesis, first, since there were no organisation or inventory of LuRs comprising 3D components, we decided to propose a specific organisation of LuRs comprising 3D components highlighting their vertical and semantic aspects. Second, by identifying and extracting spatial components of 3D LuRs from descriptions from planning documents, we specified key parameters required for modelling 3D LuRs. This part has been done manually by reviewing more than a hundred 2D/3D LuRs and **eighteen** 3D LuRs have been inventoried. Third, we applied a use-case and proposed using geometric modelling approaches to model LuRs in 3D based on the identified key parameters for **twelve** 3D LuRs. Then, we verified whether the results were meaningful to decision-makers based on a discussion with planning authorities at DELWP. Finally, through designing and developing a web-based planning permit prototype, the automation of modelling LuRs and detecting all potential LuRs' conflicts was tested and evaluated for **five** selected LuRs (i.e., height limits, energy efficiency protection, overshadowing open space, noise impacts, and overlooking). The selection of LuRs at this stage was in a way that includes at least one of the geometric modelling approaches (i.e., extrusion for height limits, sweeping for noise impacts, CSG for overlooking, and B-Rep for energy efficiency protection, overshadowing open space) specified for modelling 3D LuRs. The prototype proved the possibility of automating 3D geometric modelling and conflict detection stages for all LuRs, and the results confirmed the hypothesis is **true** if the model contains some specific geometric and semantic information.

This brings us to the second research question i.e., "**what are the required geometric and semantic information to automate the 3D modelling and verification of LuRs when various sources of information (e.g., BIM, 3D city models, and planning maps/information) are integrated?"**.

To answer to this question, this study hypothesised:

To automate 3D modelling of LuRs and detecting LuR's potential conflicts, at least we need:

1) **Position and shape of the 2D land parcel (i.e., cadastral boundary) and the proposed and existing 3D buildings including their composing elements under interest (e.g., walls, windows, balcony, terrace, patio, roof, private open spaces, rooftop solar panels), and**
2) **For all possible LuRs,**
   2A. Spatial extent of LuR restrictions (e.g., distance, angle), 2D planning zones (polygons) including overlays and public open spaces;
   2B. Semantic information such as LuR name, name and category of planning zones (e.g., capital city zone/ general residential zone/ street/ railway line), and category of proposed buildings (residential/commercial); and
3) **Contextual information for specific LuRs such as specified dates and times for checking overshadowing.**

To address and verify this hypothesis, based on LuRs' characteristics and their description, based on LuRs' characteristics and their description within planning regulatory documents and guidelines, first, the level of information need including the geometric and semantic requirements has been specified by considering all required data for all LuRs including the spatial extent of LuRs, planning and zoning information, cadastral data, proposed development, and existing buildings. The requirements specify the minimum information required to automate 3D modelling of LuRs and detecting LuRs' potential conflicts. Second, we verified whether the results were meaningful to decision-makers based on a discussion with planning authorities at DELWP. Through a discussion with planning authorities at DELWP, the proposed level of information need proved that we need at least:

- The category of proposed buildings, spatial extent of LuR restrictions position and LuR name, 2D planning zones (polygons) including overlays, and name and category of planning zones **for all LuRs**,
- Shape of the 2D land parcel (i.e., cadastral boundary) **for side and rear setbacks, street setbacks, north-facing windows, daylight to existing windows, daylight to new windows**,
- Windows for **north-facing windows, daylight to existing windows, daylight to new windows, overlooking, noise impacts, and flooding limits**,
- Specified dates and times **for overshadowing LuRs**,
- Walls **for side and rear setbacks, solar access to open space, daylight to existing windows, daylight to new windows, north-facing windows, building height limits**,
- Private open spaces **for overlooking and overshadowing LuRs**,
- Street/ railway line **for noise impacts**,
- Balcony, terrace, and patio **for overlooking LuR**, and
- Roof including rooftop solar panels and chimneys **for height and overshadowing LuRs**.

To be more specific, it was not possible to model noise impacts LuR and detect its conflicts automatically without having a model in which habitable room windows are not specified or overlooking conflicts could not be verified automatically without having a model that does not specify habitable room windows and private open spaces in the proposed and existing buildings. Finally, the proposed level of information need has been validated for **five**

LuRs based on developing a web-based prototype (as proof of feasibility) and the results showed that the hypothesis is **true**. For example, for modelling and verifying noise impacts LuR automatically, as specified in the conceptual framework, at least we needed the spatial extent of overlooking LuR, habitable room windows of proposed and existing buildings, name and category of planning zones including street zones, and private open spaces of existing buildings.

Contribution to Knowledge

This research work has been devoted to modelling LuRs comprising 3D components as part of 3D city objects and verifying them to detect LuRs' spatio-semantic conflicts automatically. To have a better view in the sense of comparison, Table 6.1 summarises the main aspects of this thesis and three groups of authors focusing on automating the process of detecting potential LuRs' conflicts to support issuing planning/building permits.

Table 6.1 – Comparison of related literature with this thesis

Literature	Reviewed LuRs	Any Framework or Workflow	3D LuRs' Modelling and the approach to integrate it	Level of Information Need	Conflict Detection Method
Noardo et al., (2022b, 2020b, 2020c)	Building height limits; Dimensions; Setbacks (overhang and tower ratio).	A GeoBIM workflow focusing on BIM-GIS integration and decision-making	No	Limited to rule-based checking requirements	Extracting the required geometries from BIM data and developing tools/algorithms to assess LuRs
Olsson et al., (2018)	Building height; Building footprint area; one visual criterion.	No	No	Limited to rule-based checking requirements	Developing tools/algorithms for detecting the conflicts
Van Berlo et al., (2013)	Maximum allowed volume; Maximum percentage of the built area; Maximum allowed noise value.	No	Limited to 3D representation within 3D city models and converting it to IFC	Limited to rule-based checking requirements	Using Solibri Model Checker to detect the conflicts during the design stage by architects
This Thesis	Twelve 3D LuRs	A conceptual framework for automatic 3D modelling and conflict detection of 3D LuRs	3D CityLuR formed independent of IFC/CityGML and then combined with other sources of information automatically	Two categories for automatic 3D modelling and conflict detection	Using clash detection as a generic approach applicable to all the modelled LuRs

Table 6.1 can be compared with the proposed approach in this thesis from various points of view as follows:

- All authors focused on developing different tools for extracting geometries from BIM design and detecting LuRs' conflicts to support issuing building permits automatically. Developing tools/algorithms to automate the conflict detection for each LuR makes it challenging to adapt the proposed approach and apply it to other jurisdictions.
- Since LuRs have different characteristics, a tool needs to be developed for assessing each LuR which makes it nearly impossible to reach a generic approach to assess all LuRs.
- Tool developments and the geometry extraction from BIM design extensively depend on the complexity of the BIM design which makes it nearly impossible to apply the tools to various designs with different complexities.
- Finally, except Van Berlo et al. (2013) which tried to represent a limited number of LuRs in 3D (for visualisation purposes, without providing any details of the representation procedure), no research can be found focusing on 3D modelling of LuRs as part of 3D city models.

As a general comparison, except Van Berlo et al. (2013) which tried to represent a limited number of LuRs in 3D (for visualisation purposes, without providing any details of the representation procedure), no research can be found focusing on 3D modelling of LuRs as parts of 3D city models. This Ph.D. research provides a foundation to reach a generic approach for detecting LuRs' spatio-semantic conflicts automatically by modelling LuRs in 3D (for twelve 3D LuRs) with no need to develop tools/algorithms for assessing each LuR and extracting geometries from buildings in BIM or 3D city models. In addition to what was discussed, the other contributions of this thesis can be indicated as follows:

The first attempt at modelling 3D LuRs as part of city objects is the key contribution of this research since after reviewing more than a hundred scientific peer-reviewed journal/conference papers, no such proposal can be found in the scientific literature or practices. The procedure of specifying the minimum number of key parameters and accordingly proposing different geometric modelling approaches can be applied to any jurisdiction and can be utilised as a source of inspiration for similar research studies and projects. As the first attempt, this thesis also highlights the application of modelling/visualising LuRs in 3D in land administration and 3D cadastre domains by enriching 3D zoning with the 3D representation of 3D LuRs.

The three-stage conceptual framework that organises and proposes a generic procedure for managing/interacting with 3D LuRs leading to detecting LuRs' potential conflicts automatically should be highlighted as another contribution of this thesis. As an original framework, it proposes a generic approach for modelling LuRs in 3D, combining them with other sources of information, and verifying the LuRs automatically.

This research proposed and formalised the level of information need for modelling and combining 3D LuRs with other sources of information (e.g., BIM, city models, and planning maps/information) for the specific purpose of issuing planning permits. The level of information need has also been proposed and formalised for verifying 3D

LuRs to detect LuRs' potential conflicts automatically. This is the first attempt to consider the level of information need for a purpose beyond BIM applications (i.e., for verifying 3D LuRs to detect potential LuR conflicts automatically) that is applicable in land administration and urban planning domains.

Finally, the developed innovative web-based planning permit assessment prototype (as proof of feasibility) for automating the process of modelling and conflict detection of 3D LuRs opens the door to new market and technology development applied to 3D land administration domains. This aspect has been confirmed through the collaboration we had with Bentley Systems as one of the leaders in digital infrastructure technologies. Thus, future planning permit assessment studies could thus benefit from the developed prototype and encountered challenges (e.g., integrating different sources of information, modelling 3D LuRs, and detecting LuRs' potential conflicts). Planning authorities, as the lead beneficiary of this prototype, can utilise it for the early decision-making process for issuing planning permits.

Future Research

The result of this thesis brings out a set of perspectives for future research in 3D geo-visualisation and land administration.

1) In this thesis, the proposed approach for modelling LuRs in 3D and verifying them to detect LuRs' potential conflicts is tried to be written generically. This approach can be adapted for different being utilised in a Canadian context by considering the differences in the LuRs' descriptions and guidelines. However, it is not tested and validated within other jurisdictions (e.g., in Canadian context) with different kinds of applications (e.g., urban analytics). Future research is needed to reach a generic approach for modelling and verifying 3D LuRs in different jurisdictions.
2) In this thesis, the key modelling parameters are extracted manually mainly from textual regulatory documents (e.g., planning scheme ordinance). Identifying the LuRs' key parameters automatically and converting them to a machine-readable format is another possible future work of this research.
3) Based on the identified key parameters, this thesis proposed multiple explicit and object-oriented geometric modelling approaches that could be utilised to model 3D LuRs automatically (such as extrusion, sweeping, CSG, and B-rep). However, space-oriented modelling approaches such as voxel modelling and their applications in automating the representation of 3D LuRs based on the identified key parameters can be investigated in future research.
4) Due to the tight schedule for Ph.D. studies, this research has not extensively addressed how the modelled LuRs can be stored and integrated with a standard approach using trending 3D formats (e.g., IFC, CityJSON, CityGML). The integration of modelled LuRs with other city objects from the standardisation perspective can be an important point to address in future related works and research.
5) This Ph.D. research focuses on the city-scale 3D LuRs and their potential conflicts within city-scale datasets. Extending the number of LuRs to include BIM-based required checks (e.g., internal conflicts like internal views, area limits) and testing more city-scale LuRs (e.g., building separations, setbacks, daylights) can be considered as the future research for this thesis.

6) This research does not address the BIM-GIS integration challenges which still need to be explored. Moreover, due to the importance of having access to 3D city models including existing buildings and city furniture for verifying 3D LuRs, developing computational methods for extracting required geometries from available image/LiDAR-derived data need to be considered for future research and developments.
7) In this thesis, 3D spatial analysis (e.g., clash detection), 3D visualisation, and their requirements have been addressed for a specific purpose of managing 3D LuRs subject to planning approval and building subdivision process. Future research is required to address and adapt 3D spatial analysis and 3D visualisation and their applications in other domains (e.g., building design within BIM, 3D urban analytics within 3D city models, 3D cadastre, and 3D land administrations).
8) This Ph.D. thesis focused on responsible authorities (i.e., councils and planning ministry) as the main beneficiary users of the proposed conceptual framework and the developed prototype. However, this Ph.D. findings can also be beneficial for other sorts of users. It can be utilised by developers like architects and developing companies for designing new developments or land surveyors for the building subdivision process. Furthermore, it can be beneficial for citizens and land buyers to better understand and see the restricted spaces in their properties' proximities. All these sorts of stakeholders and users can be approached for the usability and validation process in future related works and research.

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