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Assessing the environmental impact of 3D public law restrictions

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ABSTRACT

The needs of modern societies require, on the one hand, the most efficient exploitation of land by individual stakeholders and, on the other hand, have set up a variety of restrictions and regulations for the public benefit. Such restrictions are steadily growing in number and apply in various areas. Given the technological development in the construction sector, complex proprietary relations emerge in overlapping private and public rights. Cadastres constitute the core of land administration systems, gradually evolving to development tools that provide multi-purpose land related information. Within this context, incorporation of Public Law Restrictions (PLRs) to cadastral systems is considered a step towards the development of integrated land administration systems. Internationally, PLRs are usually registered in separate registries, under different types and formats, depending on the competent body/authority. These PLRs include, among others, restrictions regarding environment and nature protection, water protection, spatial and land use planning zones, cultural heritage, public infrastructure corridors and zones, public easements/servitudes and mining rights. Until today 3D registration and visualisation of such PLRs is mostly discussed at research level, mainly due to the variety of fields related to each PLR, the need of quantifying qualitative components or "translating" physical attributes to legal restrictions and 3D volumes, as well as to the variety of responsible authorities and types of regulations. This paper focuses on identifying PLRs that pertain either explicit or implicit 3D characteristics, emphasising on the PLRs related to the development of the Trans Adriatic Pipeline (TAP) project. This paper aims to identify the nature of 3D PLRs, based on the legal requirements regarding environmental components' analysis and mapping defined in Environmental Impact Assessment (ESIA) studies, and to investigate the possibility of compiling 3D environmental models from recorded ESIA data. Economic implications of 3D PLR approach is also considered, at qualitative level, in terms of impact on land value when 3D restrictions are imposed, and regarding the cost-effectiveness of drafting ESIA studies showing 3D PLRs.

1. Introduction

Following the structure of traditional cadastral systems, 3D Cadastre research emphasises on stratified real property rights and restrictions that apply, primarily, to residential buildings and, secondarily, to infrastructures, based on Private Law. Although this approach covers a great portion of Land Administration requirements, it does not exploit the capabilities of 3D Cadastre in full. Specifically, the domain of statutory imposed regulations (or restrictions) on land, known as Public Law Restrictions (PLRs) are usually ignored. However, PLRs affect land management to a significant extent as their number is growing rapidly, while legislation assigns them vertical characteristics, either directly, or implicitly in terms of non-geometrical, physical characteristics (Kitsakis and Papageorgaki, 2017). The 3D nature of PLRs, along with their range of applications have been discussed by several researchers in literature. Navratil (2012), discusses the consequences of PLRs on 3D cadastral context, while Kitsakis and Dimopoulou (2016) identify the range of existing 3D PLRs, also presenting characteristic cases of 3D PLRs within Greek law. This work was further expanded by a case study that presents the interrelation between 3D PLRs for the development of major infrastructures (Kitsakis and Dimopoulou, 2017). The relation of 3D PLRs with environmental protection, especially groundwater protection, is discussed by Kitsakis and Papageorgaki (2017).

Environmental protection has attained national and international attention, being constitutionally protected, while, along with sustainability, is among the development goals set by the United Nations (United Nations, 2015). Physical environment constitutes a complex system of interrelated components such as soil, surface and groundwater, fauna, flora and landscape that cannot always be quantified, while not all relations between such components can be defined. Therefore, environmental protection legislation usually creates a dense, complex fabric of regulations, based on specific cases. Environmental

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protection constitutes one of the main fields of state interventionism, imposing various types of restrictions and responsibilities on land (Siouti, 2011). Development of major infrastructure projects implies significant changes on natural environment and entails environmental risks. To mitigate such risks and compromise environment protection and economic growth, environmental restrictions are imposed either directly defined in 3D, by reference to height, depth, volume, or implied, e.g. groundwater protection depends on the above-lying soil characteristics. Exploitation of 3D models in case of infrastructures has been proposed by several researchers, e.g. Döner et al. (2010), Vandysheva et al. (2011), as well as in environmental applications and in Environmental Impact Assessment studies (Stoter et al., 2008; Danese et al., 2008; Kurakula, 2007; Sheng, 2011; Heldak et al., 2012; Ducci and Sellerino, 2013), fostering public participation, flexibility in planning options and efficient decision making (Lai et al., 2010). On the other hand, objections to the use of 3D models are raised, referring to the level of detail of 3D models, cost, system architecture requirements, as well as data accuracy, scale consistency and completeness, so that results' reliability and accountability is ensured (Lai et al., 2010; Gonzáles, 2012). In western countries, PLRs gradually grow in number and their content is related to multiple and heterogeneous parameters. This leads to increased requirements for clear and unambiguous definition and representation of PLRs' extent and content, thus intensifying the need of employing 3D modelling techniques. Technological advances in the field of 3D data acquisition, modelling and management provide time and cost-effective solutions to assess limitations and impact of a project's development early at planning stage. Hence, it enhances decision-making process by avoiding revision of a project's development due to inexpediencies related to vaguely defined 3D PLRs. Contribution of 3D spatial information technology to environmental studies is acknowledged by researchers, and investigation of the development of 3D Environmental Impact Assessment (EIA) for improved delivery of EIA studies is conducted (Loh et al., 2007; Danese et al., 2008; Ngo et al., 2014; Wróżyński et al., 2016)

This paper builds on previous work of Kitsakis and Dimopoulou (2018), considering PLRs with environmental impact, to identify those explicitly or implicitly pertaining 3D characteristics, within the Environmental and Social Impact Assessment study of the Trans Adriatic Pipeline (TAP) project in Northern Greece. In this paper, the above-mentioned research is continued and complemented by identifying which PLRs require to be taken into account for 3D analysis and the implications of introducing 3D modelling to land value and to the compilation of environmental studies.

2. Methodology

This work builds on the findings of the research by Kitsakis and Dimopoulou (2018), identifying which PLRs would contribute to the designation of a large-scale development project if analysed in 3D, and concomitant economic implications. To achieve the aim of this paper, PLRs with 3D characteristics traced in the ESIA of the TransAdriatic Pipeline (TAP) as identified by Kitsakis and Dimopoulou (2018) are further classified[1], based on the type of these 3D characteristics (explicit, non-geometrically defined, implied). Then, current methods of examining environmental components, as stipulated in legal documentation are examined, including input data and recordings. These are compared with requirements for 3D environmental modelling as described in literature, to identify whether such data is sufficient to be used in ESIA studies. Finally, the economic aspect of 3D PLR approach is considered, both in terms of land value impact when 3D restrictions are imposed, and a qualitative assessment of the cost-effectiveness of drafting ESIA showing 3D PLRs. Methodological steps are schematically presented in Fig. 1.

[1] Classification is based on the classification made by (Kitsakis et al., 2019).

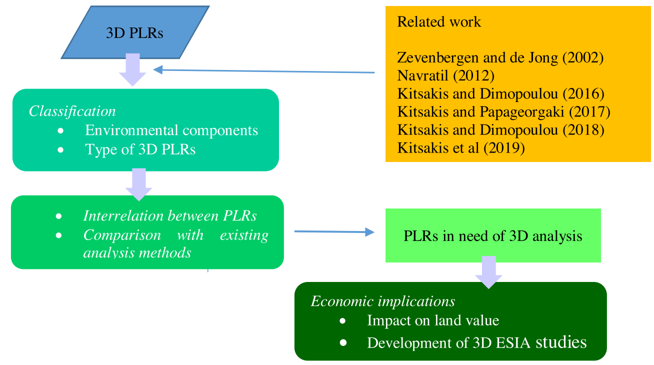

Fig. 1. Methodological steps.

2.1. Conceptual and methodological framework

Knowledge of the powers that can be exercised or of the restrictions imposed on a specific area, is of significant importance both for governments and the public. The former requires such information in order to implement and control development strategy and policies, while the latter to exploit land within the boundaries set by legislation. The need of registration of land-related PLRs to public registries is highlighted already in the work of Kaufmann & Steudler (1998), while a proposal for registration of PLRs applying in the Netherlands is presented by Zevenbergen and De Jong (2002). The spatial connotation of PLRs, especially their vertical extent, grows more important, due to the vertical expansion of land exploitation. Navratil (2012), discusses the consequences of PLRs to 3D Cadastres, investigating the applicability of 2D-based solutions. Kitsakis and Dimopoulou (2016), review the cases of 3D defined PLRs, classifying them in six legal fields: mines, archaeology, environment, civil aviation, urban planning and utilities. Characteristic examples of overlapping 3D PLRs along with the deficiencies and the limitations deriving from current (land parcel-based) legal framework are shown in (Kitsakis and Dimopoulou, 2016, 2017; Kitsakis and Papageorgaki, 2017). All of the above-mentioned research depicts that "adjustment" of 3D situations within the "indivisible land-parcel column" concept limits land exploitation capabilities. The significance of PLRs on land administration are further highlighted by the initiatives towards registration and mapping of PLRs either in themed registries (focusing on specific thematic fields, e.g. archaeology, utilities or polluted soil), or through the establishment of PLR cadastres, as applies in the cantonal PLR cadastres in Switzerland. However, the vertical component of PLRs is limited on literal descriptions and reference on legal documents. Moreover, even in case of (literally described) vertical limitations, in most jurisdictions internationally, legal framework does not allow for the establishment of PLR volumes that do not refer to the whole space above and below a land parcel.

2.2. Classification of 3D PLRs

PLRs can be classified according to various criteria, such as, in relation to the Public Law legal provisions, the purpose they serve, or the type of restriction/regulation they impose on land (Kitsakis and Dimopoulou, 2018). In this section 3D PLRs previously identified by Kitsakis and Dimopoulou (2018), are classified based on international review of the nature of PLRs' spatial characteristics (defined through explicit or implied 3D characteristics) (Table 1). To this end, parameters that are used to define 3D environmental components are identified. Such parameters are presented in Table 1 (column 3), based on the findings of Kitsakis and Dimopoulou (2018). Examined PLRs are not restricted to physical or biological characteristics (which are qualitatively or quantitatively quantifiable), but also pertain 3D regulations and restrictions related to socioeconomic environment and cultural heritage (which are, most commonly, related to legal spaces).

Table 1
3D PLRs identified in Kitsakis and Dimopoulou (2018).

Environmental category	3D environmental components	3D characteristics
Physical environment	Geology	- Lithostratigraphy - Geohazards
	Subsurface and soil	- Erosion - Compaction - Contamination - Physical characteristics of soil - Chemical characteristics of soil
	Groundwater	- Depth - Permeability of overlying strata - Contamination
	Ambient air quality	Concentration of pollutants
	Acoustic environment	Noise propagation
	Landscape quality	- Physical landscape features - Landscape historical character and buildings - Aesthetics
Biological environment	Flora	- Species growing on specific altitude - Depth of roots
	Fauna	- Protected species residing on specific altitude - Protected species residing underground
	Protected areas, sites of conservation interest	- Specific altitudes where species reside or grow - Soil and groundwater protection - Landscape conditions
Socio-economic environment	Land tenure and use	- Restrictions in vertical extent of land exploitation - Limited real property rights
	Infrastructures and networks	- Location of infrastructures and networks - Limitations due to public health issues
Cultural heritage	Archaeological sites	- Depth of underground antiquities
	Monuments	- Sensitivity of underground cultural heritage resources to vibration
	Sites of Intangible Cultural Heritage value	- Visual impact

Therefore, societal impact of large-scale development projects can be incorporated, assessed and regulated through 3D socio-economic PLRs, thus reflecting the strong societal orientation of ESIA.

It is evident from the above analysis that the three-dimensional implication of the characteristics of each environmental component does not necessarily refer to quantifiable, spatial boundaries, but also pertains characteristics that are related to physical or chemical features, or to features that are defined by qualitative terms (e.g. landscape). Given that PLRs set specific requirements on land exploitation and use, which are based on the aforementioned characteristics, the clarity of the definition of the space affected by PLRs is dependent on the spatial "clarity" of each 3D characteristic. Kitsakis et al. (2019), classify PLRs to the following categories:

- Explicitly 3D-defined (defined directly in 3D using, height, depth or volume);
- 3D-defined by non-geometrical 3D characteristics (applying to 3D space but defined by non-geometrical characteristics, e.g. soil characteristics in the case of groundwater protection);
- Implied 3D restrictions (applying to 3D space but not defined using geometrical or non-geometrical characteristics, e.g. impact of a construction on landscape view).

Table 2 presents the nature of the PLRs identified in Kitsakis and Dimopoulou (2018), according to the above categorisation.

Categorisation of a PLR as *explicitly defined in 3D*, means that corresponding legal documentation uses spatial terms to define the legal space that the restriction is imposed, such as volume, height or depth. This is also depicted in Table 2, where spatially quantifiable 3D PLRs are presented including slopes, volumes of sediment, groundwater and runoff, volumes of litter storage, construction restrictions on height and depth, and 3D restrictions for the protection of underground antiquities. *Non-geometrical* PLRs comprise restrictions that are defined by physical, chemical, mechanical or other quantifiable values. Non-geometrical PLRs can have a direct spatial counterpart (for example, soil's chemical attributes refer to a specific soil stratum), or may need to be "translated" in spatial terms (for example, the speed that water flows on land refers to a volume of soil susceptible to erosion). Within the examined case, non-geometrical PLRs include the impact of groundwater to soil stability and strength, liquefiable soil, bunded areas, protection from noise, light or vibration. *Implied* PLRs are those that are defined based on qualitative characteristics, such as visual impact of a construction to its surroundings. Identified implied 3D PLRs include those for the protection of landscape, as well as of wildlife through the construction of underpasses and overpasses. Given that PLRs on each environmental characteristic can be defined by different values, Table 2 may classify the same PLR to more than one types (for example, vegetation restrictions may be explicitly defined as "forbidden under the depth of X metres", or non-geometrically as "forbidding deep root trees").

2.3. Interrelation and spatial analysis of 3D PLRs

In the first part of this section, potential interrelations between 3D PLRs are examined, to depict the impact of each one environmental component to the others, highlighting the need of systematic recording of PLRs, instead of thematic registries. In the second part of this section, analysis tools that are currently employed to identify spaces where PLRs apply are examined, along with their capabilities and limitations compared to 3D analysis within a 3D PLR context. An example of the depiction of the variety of PLRs within a 3D PLR model, is shown in Fig. 2.

2.3.1. Interrelation between PLRs

Environmental components are intrinsically interrelated in various ways. Extending PLRs' recording from planar to 3D space implicates that such interrelations are revealed, to be taken into account within a project's designation and planning. This section presents characteristic spatial interrelations between different types of 3D PLRs, based on 3D environmental features. It is not within the aim of this work to make an exhaustive list of potential interrelations; focus is on depicting the impact of 3D PLRs on defining the complete legal situation of a land

Table 2
Classification of environmental 3D PLRs to explicitly 3D defined, non-geometrical and implied.

	3D PLRs	Explicitly 3D-defined	Non-geometrical	Implied
Physical	Impact of fault movements		✓	
	Impact of groundwater table		✓	
	Crossings below liquefiable soil		✓	
	Reduction of slope inclination	✓		
	Vegetation restrictions	✓	✓	
	Sediment containment	✓		
	Groundwater pumping and surface runoff	✓		
	Intersection of water runoff	✓		
	Bunded areas	✓	✓	
	Forbiddance of mechanical excavation	✓	✓	
	Integration of earthworks with landscape			✓
	Visual impact of spare materials			✓
	Visually unobtrusive ground structures			✓
	Vegetation screens	✓		
Biological	Prevention from erosion and flooding		✓	
	Wildlife underpasses and overpasses			✓
	Minimising working strip	✓		
	Noise/ light/ visual sources buffers	✓	✓	
	Storage and disposal of litter	✓	✓	
Socioeconomic	Cultivation restrictions	✓	✓	
	Land use restrictions		✓	
	Construction restrictions	✓		
Cultural heritage	Protection of underground antiquities	✓	✓	
	Protection of areas of high archaeological potential		✓	
	Vulnerability to vibration		✓	
	Modification of working strip	✓		

parcel, and the significance of PLRs' systematic recording. Elaborate analysis of all potential interrelations requires collaborative work by professionals from multiple scientific fields, while it would also negatively impact the development of a 3D PLR cadastre in terms of cost-effectiveness (given current technological capacities), therefore, it falls out of the scope of this work.

2.3.1.1. Physical environment. Components of physical environment are interrelated not only with the components of the rest of environmental types (biological, socioeconomic and cultural heritage), but among themselves as well. For example, the depth of the groundwater table is affects the mechanical characteristics of soil, therefore, impacts on its strength and density, thus setting soil strata appropriate or inappropriate for development of underground constructions.

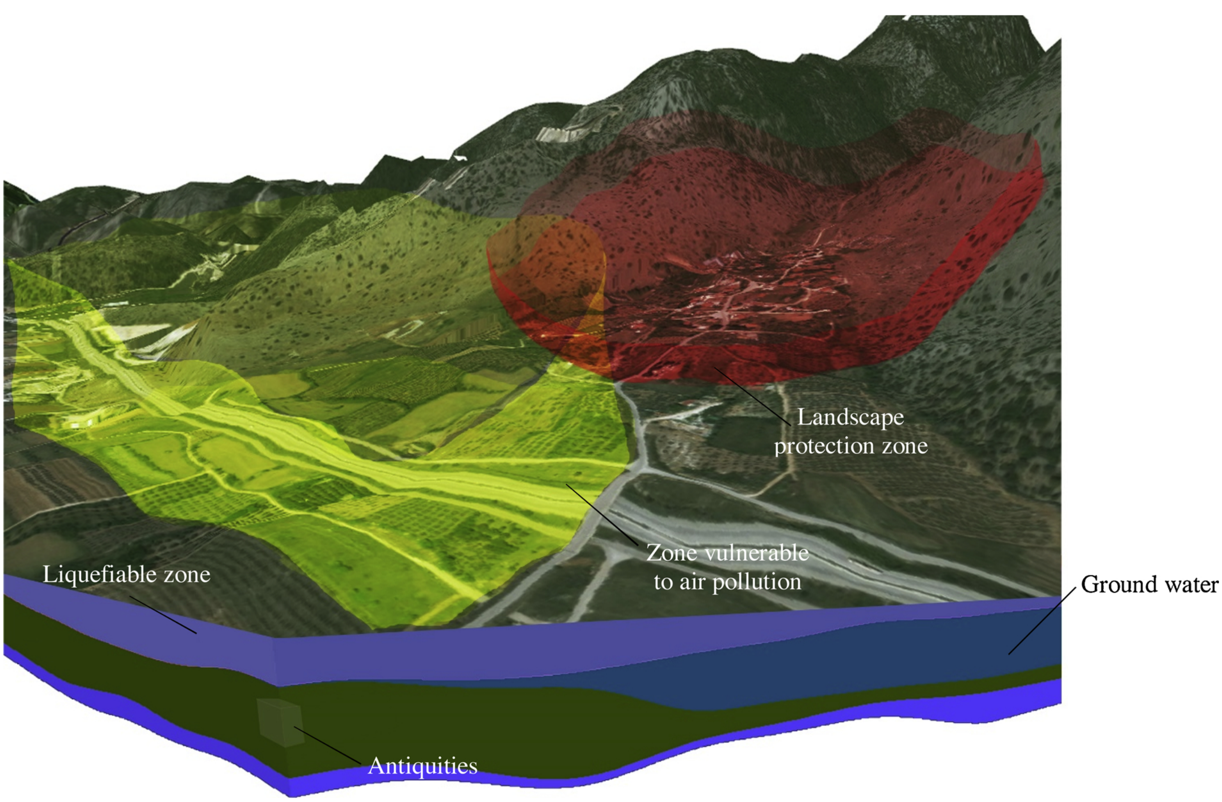

Fig. 2. Presentation of 3D PLR types.

Similarly, groundwater vulnerability to contamination is affected by the permeability of the above lying soil. Another example of intrinsic relations between components of the physical environment has to do with propagation of vibration through specific soil types, thus affecting soil structure.

Characteristic interrelations between physical and the other environmental components are the following:

- Soil properties, combined with topographical characteristics, imply risks of erosion and compaction.
- Soil types along with the abundance of water or groundwater, affects the types of flora growing within a region. Additionally, this affects the types of regional fauna.
- Landscape characteristics may require the need of visual, noise, or light barriers for protected species.
- Soil contamination is affected by the permeability of soil, thus affecting requirements on storage and disposal of litter and other waste materials.
- Restrictions on land use, cultivation or constructions due to soil, or groundwater characteristics.
- Propagation of vibration though different soil types affects the vulnerability of underground antiquities and other structures to vibration.

2.3.1.2. Biological environment. Biological environment pertains species of fauna, flora, protected areas and sites of conservation interest. At first sight, it seems that biological environment has little relation to 3D PLRs. However, 3D restrictions related to the components of biological environment refer to the altitude that species reside or grow, to the height or depth of plants and plant roots, to the height of bird migration routes, or to the depth where species residing below the ground live.

Characteristic interrelations between biological environment with the other environmental components include:

- Restrictions on cultivation, constructions and land use in the vicinity of protected areas, or areas where protected species are traced.
- Volumes where visual, noise and light barriers are required for the protection of biological environment.

2.3.1.3. Socioeconomic environment. Socioeconomic environment includes a broad range of fields such as economy, employment, income, land, infrastructure, worker rights, community cohesion, public health and safety, traffic and transport. Out of these, PLRs regulating land tenure, land use and infrastructure can be described by reference to three-dimensional characteristics.

Characteristic interrelations between socioeconomic environment with the other environmental components are:

- Protection zones around underground infrastructures depending on soil characteristics
- Cultivation restrictions, based on plants' rooting-system depth.
- Protection zones from radiation or emissions.

2.4. Analysis of PLRs within existing legal framework

This section investigates currently used methods for analysing PLRs, within ESIA process. This work uses TransAdriatic Pipeline's (TAP) ESIA documentation (Trans Adriatic Pipeline, 2013) as an exemplary research case. Data used to describe the baseline conditions is presented, followed by the analysis tools used to assess environmental impact. Input data of the baseline conditions of each environmental component along with the types of measured values are shown in Table 3 (based on TAP, 2013).

As shown in Table 3, recordings used to describe baseline conditions and to assess potential impacts of a project's development are (directly or implicitly) related to 3D characteristics. Lithological logs and DTM data are per se of three-dimensional character, while elevation data may be included in GIS maps. Concentration of contaminants, values of physicochemical characteristics are related to specific types of soil, therefore they constitute an attribute that characterises the whole volume of a specific soil type. Similarly applies in case of groundwater characteristics.

Baseline conditions as well as impact assessment are exported in 2D maps, tables, or diagrams, based on the findings of specialised environmental studies. Use of 2D spatial maps can be regarded to derive from technological limitations on 3D modelling physical environment characteristics, or from the perception that 2D maps, charts and diagrams depict more accurately and easily the examined environmental attributes (Fischer, 1997 according to Lai et al., 2010). However, it does not implicate that environmental studies are not based on three-dimensional data. Gonzalez (2012), identifies overlaying, thematic mapping and, occasionally, 3D modelling and visualisation to be the most common GIS tools used in spatial analysis for environmental impact assessment. Therefore, GIS analysis tools are used to examine environmental parameters and to present the geographical distribution of an environmental aspect and interrelate it with other aspects within a region and present them on a map. Within the examined ESIA, 2D maps show prevalent soil types, groundwater bodies, protected areas, landscape types, cultural heritage sites, or protected species within specific zones along the pipeline's centreline.

Depending on the type of each environmental attribute, 3D characteristics are taken into account within the baseline and impact assessment process. Lithological logs directly depict the depth of different soil strata which, along with soil sampling measurements, also depict the physicochemical characteristics of each soil type. Similar cases can be traced regarding groundwater sampling. Noise and air dispersion are modelled taking into account three dimensional characteristics, while measurement of noise and of air quality also relate to the 3D location of noise and air quality measurement sensors. However, noise and air dispersion models are shown on 2D noise and pollutant concentration contour maps.

In several cases, e.g. cultural heritage sites, the horizontal extent of areas characterised of high archaeological potential or protected archaeological sites, are also shown in 2D maps (Fig. 3). However, such maps can only be used to indicate the existence of a restriction within these specific locations, but neither is the content of such restriction available, nor its vertical extent. This may be also be related to other types of restrictions that may concurrently apply to the same parcel at different height or depth level. Estimation of the height where examined environmental components are traced, can only be made by overlaying 2D maps to height maps or contours.

Therefore, the main issue with the mapping of environmental components, is not only the 2D representation of environmental attributes, but the mapping of the physical characteristics per se, which does not include the restrictions deriving from such characteristics.

2.5. Economic aspects

Economic aspects of 3D PLRs cover land value impact, that reflects on land acquisition and compensation values, as well as the cost for compiling a 3D ESIA. In this section, such economic implications are investigated. Investigation of the impacts on land value and compensation is based on the documentation regulating land acquisition and compensation for the pipeline's construction, while aspects related to compilation of a 3D ESIA are qualitatively examined, by interrelating data required for compilation of ESIA, to data required for 3D environmental analysis, as described in literature.

2.5.1. Land value

Land for the development of the pipeline is acquired though purchase or through the establishment of servitudes of passage. In case that no agreement can be reached with land parcel owners, land can be

Table 3
Types of recorded data describing the features of environmental components.

	Input data	Recordings
Physical	Surface and groundwater sampling	Concentration of contaminants
	Soil sampling	Soil physicochemical characteristics
	Geological maps	Lithological logs
	Air sampling	Concentration of contaminants
	Noise measurements	Noise levels
	Landscape characterisation and Visual Analysis for main vistas regarding above ground structures	2D maps and imagery, Digital Terrain Model (DTM)
Biological	Outline of protected areas and their elements	GIS maps
	Common populations of flora species of conservation interest	Field survey, satellite imagery, rectified aerial photos, GIS data, previous survey data
	Survey and study of suitable habitats of fauna	GIS data, telemetry
Socio-economic	Identification of water sources, transmission lines, agricultural land and buildings within the project's area	GIS maps, cadastral data, utility services' maps
Cultural heritage	- Desktop study - Field research	GIS maps, field survey and recording

expropriated, or forced servitudes can be imposed. Impact on land extend on three zones and can be of permanent nature (in case of construction of permanent facilities), of temporary nature (land required only during pipeline's construction stage), or may impose permanent restrictions on specific parts of land (Fig. 4) (TAP, 2016).

Land required for the development of permanent infrastructures (located on land's surface) is stipulated to be purchased from its owners, while land required at temporary basis will be acquired under lease and will be returned to its owners after the completion of construction operations. Compensation is provided to all land subject to use restrictions or where servitudes of passage need to be established (TAP, 2016). Potential impact types on land, along with prescribed compensation are presented in Table 4.

Considering that, apart from permanent facilities which require expropriation of the whole land parcels involved, all other types of impacts refer to volumetric occupation and restrictions on land, it is clear that restricted spaces by 3D PLRs entail different compensation values. Calculation of compensatory values is also related to land categories (peri-urban land, potential development, irrigated or non-irrigated agricultural land), categories of crops, attachments on land, and transaction costs (Trans Adriatic Pipeline, 2016).

2.5.2. 3D data in environmental studies

In this section, the feasibility of introducing 3D environmental studies within the ESIA compilation is qualitatively investigated. Requirements of environmental studies within the context of ESIA are examined in relation to requirements of compiling corresponding environmental studies in 3D, based on literature research.

2.5.2.1. Physical environment. Physical environment consists of various 3D components, which have been presented in Table 2. Studies regarding baseline conditions, as well as impact assessment data of physical environment components, include 2D map representations, tables and diagrams of each component's characteristics, which are shown in Table 4. Geological maps present the dispersion of geological formations along the pipeline's route, while soil and groundwater baseline maps depict dominant soil types, along with groundwater locations overlaid on 2D region maps, and groundwater chemical conditions in the form of 2D diagrams. However, such input data can also be used in the development of 3D subsurface models (Jarna et al., 2015; Lin et al., 2017; Smith et al., 2008). Similarly applies in case of air pollution and noise; diagrams showing the value of pollutants' concentrations, in the form of tables or concentration contours are used. Concentration measurements refer to the value of the examined element (pollutant, or noise) to its specific location. Research of (Sheng, 2011) generates 3D noise and air pollution models, while (Stoter et al., 2008), exploit such measurements not only for 3D visualisation of noise contours in 3D noise maps, but extend its

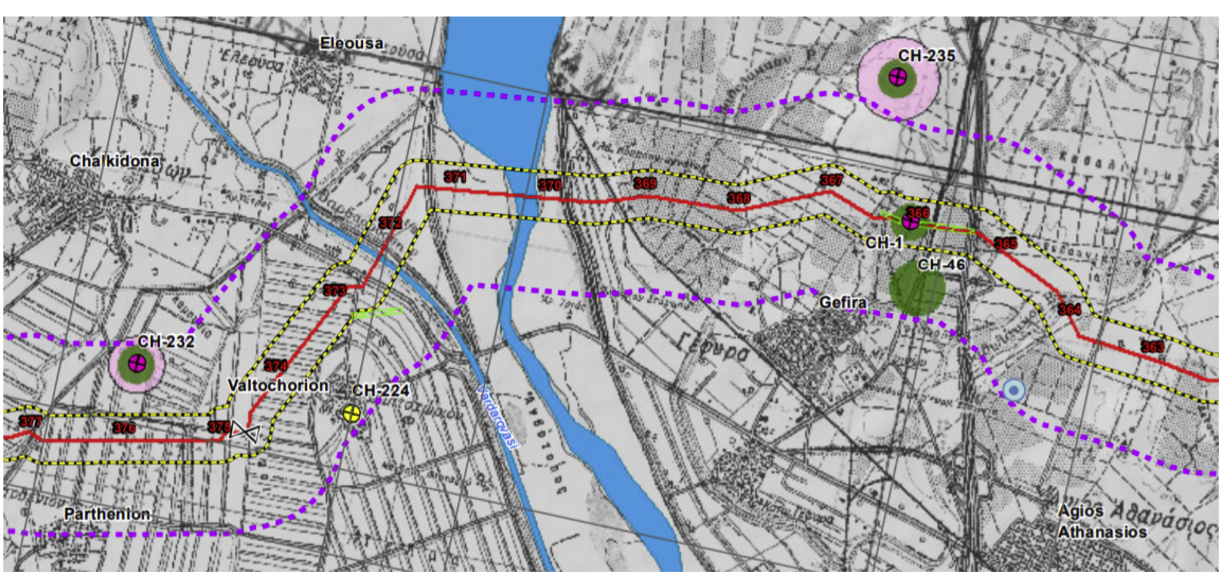

Fig. 3. Cultural heritage baseline map (TAP, 2013).

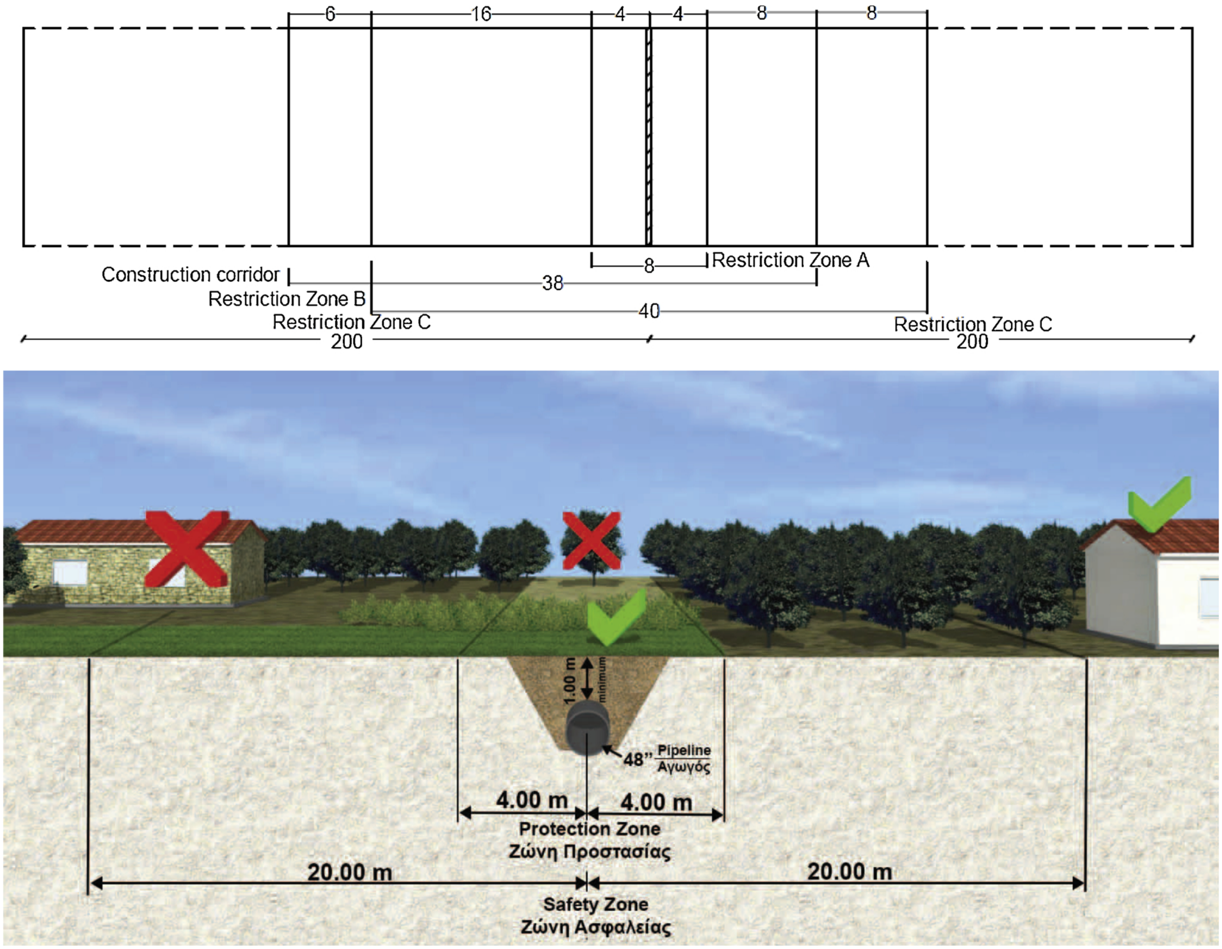

Fig. 4. *Top:* Top view of the construction corridor and restriction zones along the pipeline, *Bottom:* Cross-section view of the construction corridor and restriction zones along the pipeline. (TAP, 2016).

application to noise impact studies.

ESIA also requires landscape visual analysis to be conducted for installations with significant landscape impact (in the examined case compressor stations), exploiting view shed analysis tools in GIS combined with DTM models. Zones of visual influence of the intended structures are identified and presented in 2D maps, while the 3D model of such installations is integrated to landscape photographs to simulate the real situation after construction (TAP, 2013). Therefore, the three-dimensional character of landscape analysis is acknowledged to support ESIA landscape studies, employing 3D tools both for 3D analysis and

Table 4
Potential impact types of land and corresponding compensation (modified, TAP, 2016).

Type of impact	Type of compensation
Permanent facilities	- Purchase of land by the owner along with compensation for improvements on land at Replacement cost. - Compensation for loss of crops at full replacement value to land users
Temporary use of land	- Land Owner: Compensation for land at a rate of 25% of Land Replacement Value for 2 years rental, renewable per year until end of Construction, at 10% of Land value for each additional year. - Compensation to the Owner at replacement cost, for improvements on land. - To Land User: Compensation for lost farm income during construction period (minimum 2 years) at full replacement value.
Orphan land[1]	Case by case review
Long-term servitudes/restrictions in Zone A (No buildings of any nature, no deep ploughing, no trees with deep roots)	- In land deemed constructible: 90% of the land replacement value - In land deemed agricultural: 50% of the land replacement value - In pasture or non-usable land: 25% of the land replacement value
Restrictions in Zone B (No residential buildings)	- In land deemed constructible: 90% of the land replacement value - In land deemed agricultural: 0% of the land replacement value - In pasture or non-usable land: 0% of the land replacement value
Restrictions in Zone C (Potential restrictions to the number of buildings in the safety zone)	Case by case review

[1] Orphan land is considered the portion of a plot severed or bisected by TAP that is not directly impacted (acquired or rented by TAP) but rendered uneconomic; unviable; and/or inaccessible (either permanently or temporarily) (TAP, 2016).

simulation (Danese et al., 2008).

2.5.2.2. Biological environment. Analysis of biological environment components in ESIA baseline and impact assessment, pertains 2D maps, showing the planar extent of protected areas as well as points, or polygons showing the locations of habitats of protected species. However, given the interrelation between physical and biological environment, characteristics of the former are also taken into account during impact assessment of the latter. Consequently, three-dimensional modelling of physical environment components can be exploited also for biological environment purposes.

2.5.2.3. Socioeconomic environment. Socioeconomic characteristics are presented in 2D maps, showing land use, administrative boundaries, infrastructures and networks, economic activities, types of agricultural activities, heath facilities, education, waste disposal sites, forest use types and irrigation. Cadastral data are as well included within the data required for the presentation and analysis of socioeconomic environment. Key features and sensitive areas, such as buildings, water resources, schools, transmission lines and agricultural land are taken into account within 2D analysis, through overlaying and thematic mapping. Given the interrelation between different environmental components, analysis of socioeconomic environment relates to soil and groundwater quality characteristics, radiation, noise and air pollution levels, which are of three-dimensional character. Changes on land tenure and restrictions during construction and operation and maintenance of the pipeline are also of three-dimensional impact.

2.5.2.4. Cultural heritage. Analysis of cultural heritage characteristics can be split in two parts. The first one refers to the protection of cultural heritage sites and monuments per se, while the second refers to the protection of the landscape that cultural heritage sites are situated (especially in case of monuments, or cultural heritage sites lying on ground level). Known cultural heritage sites are presented on 2D maps, while potential subsurface structures are indicated by desk study analysis, using historic maps and aerial image analysis (TAP, 2013). Identification of cultural heritage may also be conducted by field survey, where vertical characteristics are required to be recorded. In case of archaeological findings during construction stage, chance finds procedure is followed, where GPS location of archaeological antiquities is, among others, recorded. However, 3D analysis is limited to the visual impact of constructions to cultural heritage, similarly to landscape visual analysis, and cultural heritage PLRs are limited in 2D presentation, as polygons of protected archaeological sites or areas of high archaeological potential, or as points, showing the location of monuments, archaeological sites and sites of intangible cultural heritage. Relation to physical environment characteristics also applies in this case, both for in-situ preservation of underground cultural heritage findings (impact of vibration), and for cultural heritage sites on ground level (impact of dust and air pollution).

3. Discussion

Previous sections showed the three-dimensional aspects of environmental components, as well as the restrictions that relate to environmental component's attributes. In this context a number of PLRs defined by reference to non-geometrical and implied attributes have been identified, while others were classified in multiple categories, depending upon the respective case.

Since environmental components are strongly interdependent, the same applies to PLRs. Therefore, requirements on an environmental attribute can be affected by those on another (e.g. requirements on the level of concentration of contaminants on groundwater, are affected by those applying to soil). Interrelation between the different environmental attributes also brings out the need to interrelate different PLRs, such as explicitly defined 3D PLRs with implied 3D PLRs.

In this paper the ESIA study was used within the relevant national legislation, as research and testing ground for evaluating 3D data registration impact (with direct, non-geometrical or implied 3D connotation). Even though environmental studies record and display two-dimensional data, their actual management must include the three-dimensional characteristics of the real world. The lack of such management also has an impact on the economic dimension of a project, as not all its dimensions are revealed. Restrictions which are based solely on qualitative characteristics of the environment's components not fully attribute the 3D form and possible overlapping of PLRs (protected areas, habitats, archaeological sites, groundwater bodies and soil types are among the 2D spatially defined environmental characteristics). Particularly in some environmental cases, such as noise and air/ or water pollution dispersed above and/or below the ground, implementation of multi-level based 3D modelling is considered necessary for a complete and economically viable solution. Therefore, considering the 3D mapping of PLRs as necessity, involves economic implications. These can be distinguished to those related to the impact of 3D PLRs to land values, and to those related to the additional cost for the compilation of 3D PLRS in ESIA studies. Impact of 3D PLRs on land value is challenging, however difficult to be assessed, due to the lack of 3D cadastral Rights, Restrictions and Responsibilities (RRRs), thus restricting delimitation of 3D volumes.

In the case study examined, it seems that the establishment of servitudes of passage and of restriction zones along the pipeline's centreline, constitute the sole 3D-related PLRs quantified in terms of land value. Land affected by the development of the pipeline is mainly agricultural (about 80% of the total land), including pastures, irrigated agriculture land, fruit trees, olive groves and vineyards (TAP, 2013). Areas of peri-urban land (within 500 m buffer around urban land) constitute another part of affected land. Consequently economic impact of vertical PLRs due to the pipeline's development cannot be easily assessed, given that stratification capabilities on agricultural land are limited. Limitations imposed to Zone C are the sole 3D PLRs that are related, to an extent, to urban environment, but provision for compensation through case by case review, does not provide any indication of how 3D PLRs within urban environment are assessed. Provisions for compensation regarding the establishment of servitudes of passage and restrictions on agricultural land, constitute a mere indication of how 3D socioeconomic PLRs are assessed. Based on the compensation values shown in Table 4, volumetric restrictions in Zone A, B and C are progressive and depend on the allowed land use: restrictions on constructible land entail high replacement rate of compensatory value, while they are reduced when imposed on agricultural or pasture land. In case of restrictions in Zone B, compensation is provided only for restrictions imposed to constructible land. Restrictions only refer to the maximum depth of agricultural activities or the construction of buildings, only referring to the lower level of the restriction.

For the rest of the socioeconomic environmental components, restrictions are not provided in 3D. For example, for the protection of archaeological antiquities, restriction zones are defined on horizontal plane and implemented based on total or partial expropriation of parcels. Similarly applies in case of habitats and protected areas. Even when these areas are not privately owned and their intrinsic characteristics do not allow for land use stratification, volumetric restrictions affect neighbouring land property, especially in terms of landscape protection. However, the effect of this type of PLRs is difficult to be evaluated. Jaeger (2006), claims that although such restrictions entail high benefits to the society, these benefits accrue to the general public rather than the landowners, thus reducing the value of land. According to Michael and Palmquist (2010), restrictions have different impact on land value; restrictions on land development capabilities reduce the value of vacant land, while they are of lesser impact on improved land.

In most cases, although the analysis of a significant number of environmental components is based on 3D characteristics, especially those

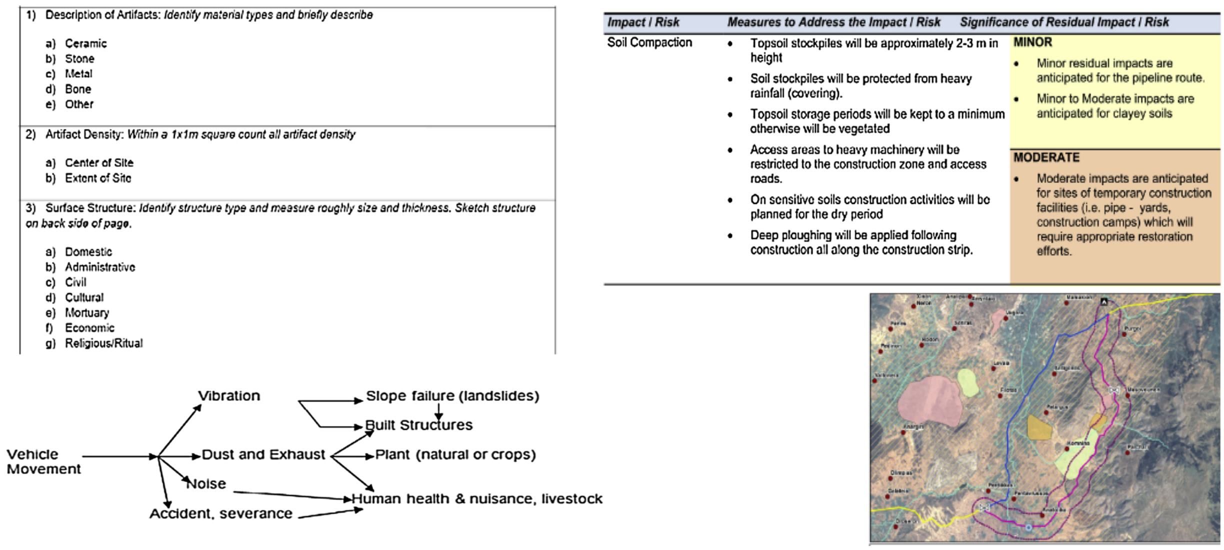

Fig. 5. *Top left*: Site observation checklist (TAP, 2013), *Top right*: Residual Impacts – Subsurface and Soil - Construction Phase (TAP, 2013), *Bottom left*: Effects of vehicular movement during developmental activity (https://eco-intelligent.com) *Bottom right*: Rerouting in relation to PPC concession area, active/planned mines and known lignite deposits (TAP, 2013).

related to physical environment, it is reflected on two-dimensional maps, or descriptive charts and diagrams (Fig. 5), with the exception of landscape protection and visual amenity. In such cases, 3D analytical methods are reflected in three-dimensional photomontages of proposed developments, yet such data are suggestive and can be less attractive (Danese et al., 2008). As mentioned in section 2.4.2, several research studies employ 3D modelling techniques to represent physical environmental characteristics, such as soil and groundwater. Despite these methods, they are mainly used to depict each environmental characteristic in 3D, but not the restrictions related to it. By using 3D methods to map groundwater vulnerability to contamination, Ducci and Sellerino (2013) show the efficiency of modelling and visualising environmental PLRs in 3D. The contribution of 3D tools in environmental modelling is acknowledged in Hong Kong, where a 3D platform is proposed to represent designed projects in 3D environment (Ngo et al., 2014). This approach mainly focuses on presenting a realistic 3D representation of an intended development, and its alternatives, along with their environmental performance using illustrations, graphics or multi-media images or videos (Environmental Protection Department Government of Hong Kong, 2004). 3D visualisation of mitigation measures can also be implemented. The aim of this approach is to foster public participation, so that the impact of planned developments can be better understood, and broad public consensus can be achieved. Although 3D visualisation refers more to the proposed development, its alternatives and mitigation measures per se, and less to the restrictions deriving from environmental characteristics, it clearly reflects both the efficiency and the feasibility of drafting 3D ESIA studies.

Although 3D environmental studies are compiled for physical environment components (also covering several aspects of biological environment), analysis of socio-economic as well as of cultural heritage attributes, is not based on three-dimensional analysis. Restrictions are defined based on horizontal plane, regardless of their vertical characteristics. Land tenure restrictions along pipeline's centre-line constitute the only restrictions that extend on 3D space and are assigned explicit 3D definition. Nevertheless, such restrictions are not imposed within a 3D RRR framework, thus introducing ambiguities regarding their extent. Both socioeconomic environment and cultural heritage studies, according to the requirements set by ESIA framework, do not pertain three-dimensional characteristics. Therefore, development of three-dimensional studies on these fields would introduce special requirements regarding data acquisition and mapping which would increase related cost.

4. Conclusions and further research

Preceding analysis has shown the complexities and the interrelation between environmental components in 3D space, as well as the environmental restrictions that are based on such components. Emphasis was given to the three-dimensional aspects of such restrictions. It has been identified that current environmental analysis tools employ 3D characteristics of several environmental components, mostly those referring to physical environment. However, the outcomes of such analysis reflect the value of each examined environmental component's attribute in 2D maps, charts or diagrams, while not reflecting the restrictions that derive from each attribute's value. Given the strong interrelation between different environmental components, several attributes of physical environment, such as soil and groundwater characteristics, are also applicable to the rest of the environmental components, especially biological environment. Conversely, socio-economic environment and cultural heritage PLRs are mostly imposed on horizontal plane, even though they are of three-dimensional character. Socioeconomic land tenure restrictions are the only which are assigned spatial connotation, in terms of land use restrictions imposed on specific depth.

Economic implications of 3D PLRs were also investigated in this work. Such implications are of dual character. On the one hand they include the impact of 3D PLRs on land value, while, on the other, they reflect the economic impact of compiling 3D ESIA studies. In the former case, only the restrictions deriving from servitudes of passage pertain 3D characteristics and entail compensation of the land owners and the land users. Compensation values reflect the evaluation of the restricted 3D volumes and are based on the categorisation of the land parcels, as well as on their exploitation. Considering the economic implications of drafting studies referring to 3D aspects' modelling, it seems that there is a variety of environmental aspects that are already examined taking into account their three-dimensional characteristics, such as physical environment's components, which can also be extended to cover aspects of biological environment as well. Components of the socio-economic environment (apart from the above-mentioned land tenure restrictions) and of cultural heritage are the most difficult to be "translated" to spatial volumes, given that their examination is based on qualitative studies and their spatial connotation refers, when applicable, in horizontal plane.

Limitations deriving from the lack of 3D cadastral framework, in terms of allowing vertical subdivision and imposing of volumetric

RRRs, complicates the problem, since PLRs referring to spatial volumes cannot be addressed by existing real property rights (which allow only for specific cases of real property stratification within the concept of "indivisible" ownership of land above and below a land parcel). This also relates to the discussion regarding the nature of restrictions imposed by Public Law on land ownership, which affects land expropriation and compensation procedures. Enhancing ESIA studies with 3D models presenting not only a 3D depiction of proposed developments, but the 3D impacts and restrictions that apply within each proposed development's vicinity should be considered, in order to increase public engagement on environmental issues and reduce public objections and litigation. Classification of PLRs is also required for them to be integrated within land administration modelling systems, e.g. the Land Administration Domain Model (LADM), or to be modelled within PLR Cadastres and thematic registries.

Integrating 3D PLRs within the Greek legal and cadastral framework, constitutes a challenge for the ongoing (traditional parcel-based) Hellenic Cadastre (HC) project. It is evident that cadastral survey legislation for the HC survey does not provide for PLRs' registration; therefore, considering about integrating 3D volumes into the current stage of the HC project, seems to be premature. However, the "open cadastre" principle (meaning that the HC database is open to be enriched with further information when the project is completed), leaves room for introducing registration of 3D real property objects, as well as of integrating PLRs within the future cadastral framework. Hence, the need for an integrated cadastral and PLR system, with the prospect of incorporating the 3rd dimension emerges, to efficiently support sustainable and development policies.

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