ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XII-4/W2-2026
10th International Conference on Smart Data and Smart Cities (SDSC), 29 September–1 October 2026, Sofia, Bulgaria

The use of conceptual modelling in map composition and cartographic analysis: Towards a more intelligent GIS

Anna Christina Daverona [1], Dimos N. Pantazis [1], Dionysia Georgia Ch. Perperidou[1]

[1] SOCRATES LAB (Society for Organizations Cartography Remote sensing / Road design and Applications using Technology / Transport engineering on Earth and Space) Dept. of Surveying and Geoinformatics Engineering, University of West Attica, Egaleo, Athens, (adaverona@uniwa.gr, dnpantazis@uniwa.gr, dgperper@uniwa.gr)

Keywords: Map, cartography, conceptual model, spatial database, graphical attribute, smart cartographic data

Abstract

The conceptual data models (CDMs) are generally used during the design phase of a spatial or no spatial database (SDB). Although their role in supporting the design phase of a spatial data base is of great importance, their role within GIS environments has not been sufficiently explored. This paper presents a part of ongoing research which leads to more advanced and intelligent GIS software procedures. The first aspect concerns the map layout/composition during the design phase, which leads to a more intelligent map composition workflow. The second aspect concerns spatial queries on cartographic databases. Those queries could combine logical attributes, graphical characteristics and topological relationships. In this frame it is also analyzed the importance of the graphical attributes (e.g. color of polygons) in spatial queries. Overall, this research has as a principal target to demonstrate how the integration of conceptual models with GIS procedures can enhance both the design and analytical capabilities of spatial information systems, moving beyond the limitations of standard GIS possibilities concerning the spatial queries and the cartographic composition.

1. Introduction

The use of digital or paper maps is more than necessary in all steps of urban/city planning (and not only). The cartographic data representing a city on two or three dimensions, may help:

a) on the development of new urban planning projects,
b) to renovate urban regions,
c) on creation of new green spaces,
d) to the resolution of city traffic problems,
e) to the construction of new city infrastructure etc.

In order to improve the city representation, many concepts and ideas have been developed until today: e.g. the digital twins (e.g. Yan, 2019), the 3D city models (e.g. Biljecki, 2015), the 3D cadaster (e.g. Döner, 2021), the underground city models and maps (2D and 3D) (e.g. Yan, 2018), the digital cities representations from municipal authorities (e.g. Yadav, 2024), the PPGIS (Public Participation Geographic Information Systems) (e.g. Brown, 2015) etc. The digital maps are based in most cases on spatial databases from which we extract the necessary data for their construction (Figure 1).

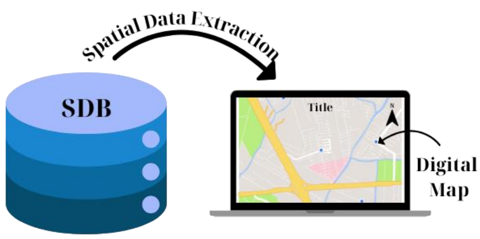


Figure 1: From spatial data base to a digital map.

The conceptual data models (CDMs) are generally used during the design phase of a spatial or no spatial database. Two are the basic tools for the development of a CDM, imposed de facto as standards: the UML (Unified Modeling Language) and the E/R (Entity/Relationship) model, with many variations.

This paper presents a part of this ongoing research which concerns the following GIS software procedures: a) the map layout/composition during the design phase, b) spatial queries on cartographic databases (those queries could combine logical and graphical attributes and topological relationships). Those queries could combine logical and graphical attributes and topological relationships. In this frame it is also analyzed the importance of the graphical attributes (e.g. color of polygons) in spatial queries.

More specifically, the first section gives a summary of the basic cartographic elements of a topographic map. The second section introduces some fundamental elements of the conceptual data models and the spatial databases design. The third section concerns the use of data models in order to design the composition/layout of a classic topographic map. The fourth section concerns the enrichment of the cartographic data with their graphical attributes. Also, it is presented the use of conceptual models as tools for spatial and combined queries using logical and graphical attribute and topological relations. The sixth section summarizes the main findings and presents the perspectives of this work.

2. Basic cartographic elements of a topographic map

A topographic (digital or paper/analogue) topographic map (Figure 2) is composed by a number of elements which are:

a) the dimensions of the paper/other material/digital space in which we will design the cartographic area
b) the dimensions of the external frame
c) the dimensions of the internal frame
d) the title of the map (up and down)
e) the scales (arithmetic and graphic)
f) the grid of meridians/parallels based on the used geodetic system
g) the geodetic system information/ellipsoid/datum
h) other geodetic/topographic information
i) the name of the editor
j) the date of the map construction/edition
k) the date(s) of revision(s)
l) the legend of symbols
m) the legend of toponymy
n) the symbol of north

o) the plan of the relation between the map and the adjacent maps of the same scale.
p) information of the raw data of the map (aerial stereoscopic photos, satellite images etc.)

A topographic map could be made from paper, plastic or other material or it could be digital. An important remark here is to mention that the representation of the content of a spatial database is not considered a map. A topographic map must have the above characteristics in order to be defined as a map.

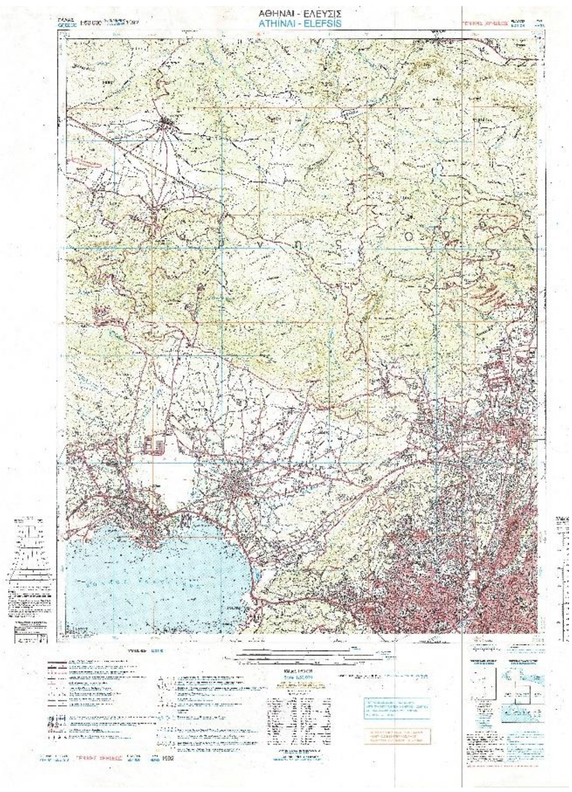


Figure 2: A topographic map of Hellenic Military Geographical Service (Scale 1:50.000)

3. Conceptual data models for spatial databases and topographic maps

For the creation of a spatial database (SDB) it is necessary, after the needs analysis phase, to create the conceptual data model (CDM). During the needs analysis, a list of the spatial entities is created. For all the spatial entities are defined their type (point, line, polygon, combination of those three) as well as their logical and graphical attributes. Data dictionary and metadata creation are included in this phase. Many GIS companies provide ready to use conceptual models for different professional domains that can be used as they are or with small or bigger modifications (Figure 3 (a) (b) (c)).

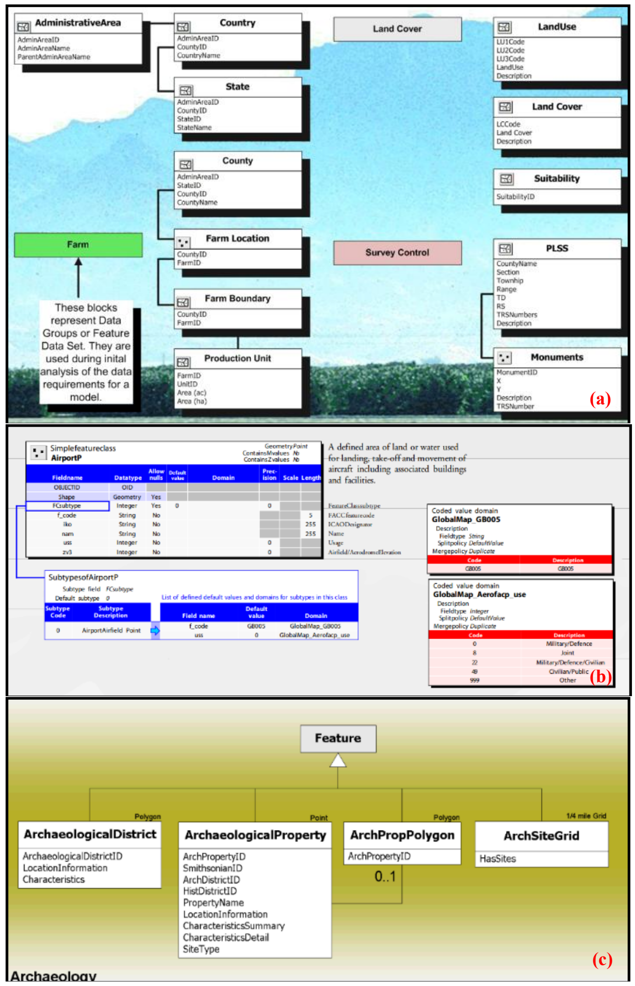


Figure 3: Part of models from ESRI company (a) An ArcGIS Model for Agriculture (https://downloads.esri.com/support/datamodels/Agriculture/AGDM_Poster.gif), (b) Global Map Data Model (https://downloads.esri.com/support/datamodels/Basemap/Global_MapDetail(Esize).pdf), (c) Historic Preservation and Archaeology Data Model (https://downloads.esri.com/support/datamodels/Historic%20Preservation%20and%20Archaeology/HistoricPreservation.gif)

Many GIS software packages incorporate their own tools in order to facilitate the design phase of a spatial data base e.g. ArcGIS Pro, Smallworld, etc.
Most GIS software is excellent for logical and physical data modelling, however there is a lack of abilities in conceptual design and thus the conceptual modelling (high-level E/R diagrams) is often done in external modelling tools first.

For limited space reasons, we are presenting only the fundamental elements of the E/R model:

a) the entities
b) the attributes
c) the relations
d) the instances (entities with specific values in their attributes)
e) the correlation numbers between the entities
f) pictograms (the graphic symbol of the point {.}, line {/} or polygon{O}, in the box of spatial entities, next to the name of the entity)

In Figure 4 it is presented an example of a conceptual model (citizen owns a land parcel) that contains all the above elements.

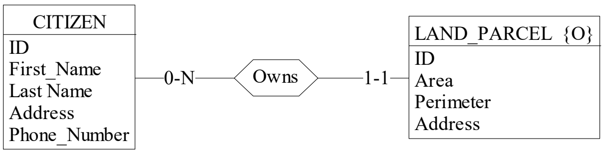


Figure 4: Citizen-Land Parcel, Conceptual Model Example

4. The design of a topographic map layout/composition using conceptual models

4.1 The ArcGIS Pro software procedure for the map layout/composition

The first procedure that is presented on this paper is to create the map layout/composition during the design phase as it happens with all the other data that is used to create a map. In order to create the map layout/composition (Figure 5) with a GIS software, which is the most common tool for a such procedure, we need to follow a quite complicated procedure independently of the software used. In order to be clear and understandable this proposal for the reader, bellow is presented analytically all the necessary steps that the user has to do to create the map layout.

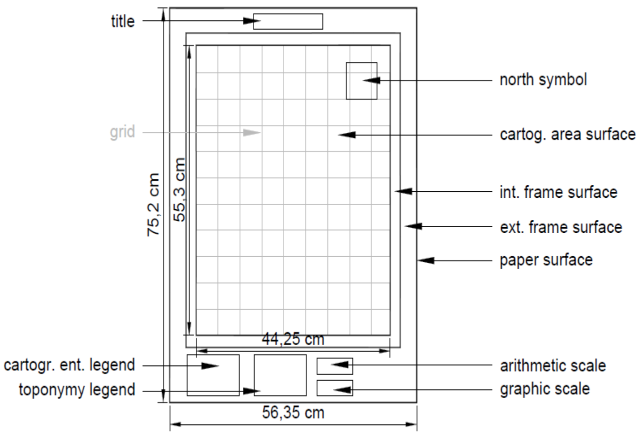


Figure 5: The basic elements of a map layout/composition.

To ensure clarity of the proposed approach, the steps that the user has to do to create the map layout are presented in detail.
The following detailed description is provided in order to highlight the complexity of the process rather than to serve as a user manual.
For example, the map layout/composition procedure in the ArcGIS Pro software is the following:

- Determine the dimensions of the paper surface
  Insert→New Layout (choose the layout) (Figure 6)

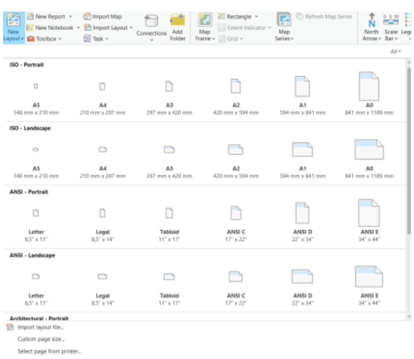
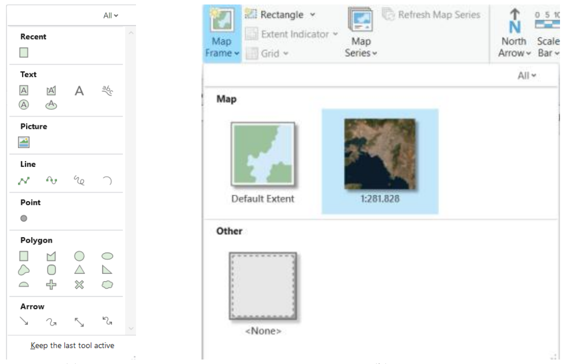


Figure 6: New Layout in ArcGIS Pro.

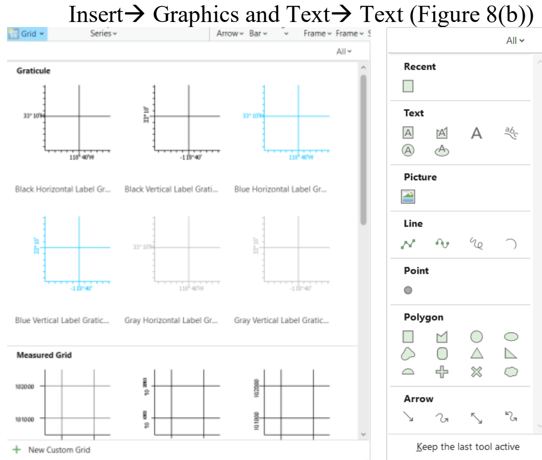
- Add the borders (external and internal frame)
  Insert→ Graphics and Text→ Select Polygon and place it in the right position using the rulers (Figure 7(a)).
- Define the cartographic area
  Insert→Map Frame (Figure 7(b))



(a) (b)

Figure 7: (a) Adding borders in ArcGIS Pro. (b) Define the cartographic area in ArcGIS Pro.

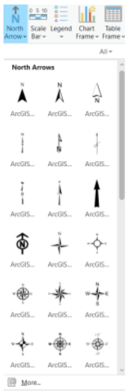
- Add grid
  Insert→Grid (Figure 8(a))
- Add secondary elements of the map
  - Title
    Insert→ Graphics and Text→ Text (Figure 8(b))



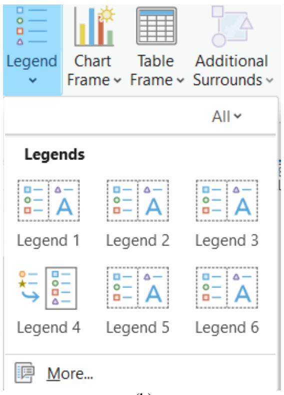
(a) (b)

Figure 8: (a) Selection of the grid in ArcGIS Pro. (b) Add title in ArcGIS Pro.

  - North Symbol
    Insert→ North Arrow (Figure 9(a))
  - Toponymy and cartographic entities legend
    Insert→Legend (Figure 9(b))



(a)

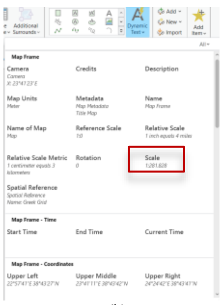


(b)

Figure 9: (a) Add north symbol in ArcGIS Pro. (b) Add legend in ArcGIS Pro.

- Scale (graphic and arithmetic)
  Insert→ Scale Bar (for graphic scale) (Figure 10(a))
  Insert→ Dynamic Text→Scale (for arithmetic scale) (Figure 10(b))

(a)



(b)

Figure 10: (a) Add graphic scale in ArcGIS Pro. (b) Add arithmetic scale in ArcGIS Pro.

The cartographic composition procedure presented above, requires from the user to know how the steps of the map's layout/composition (Figure 11) are implemented in every GIS software. This approach is a technology driven approach.

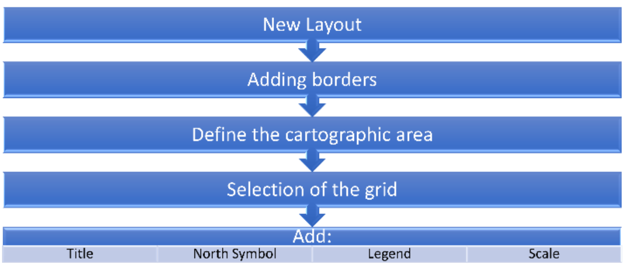


Figure 11: All the steps described above summarized in a single image.

4.2 The proposed approach

Instead of the above complicated procedure, commonly used by GIS software, the proposed approach is a user driven approach based on the CDM for the design of topographic map layout and composition.
The main idea is to transform all the fundamental elements of a topographic map - excluding the spatial entities - into meta-entities. Within this model the basic meta-entities of a topographic map (Figure 5) are the following:

a) Paper surface
b) External frame surface
c) Internal frame surface
d) Cartographic area surface
e) Grid
f) Title
g) North symbol
h) Cartographic entities legend
i) Toponymy legend
j) Graphic scale
k) Arithmetic scale

Using these entities, a meta conceptual data model (MCDM) was developed, (where data = the meta-entities of a topographic map) representing the layout of the topographic map (Figure 12). The proposed MCDM enables users to complete the attributes of the entities in the metamodel in a sequential manner. Each meta-entity (from the above list a to k) is numbered to guide the order in which the user should proceed. As a result, the process becomes straightforward, and users are not required to memorize steps during its execution. This represents the first original contribution of the present study.

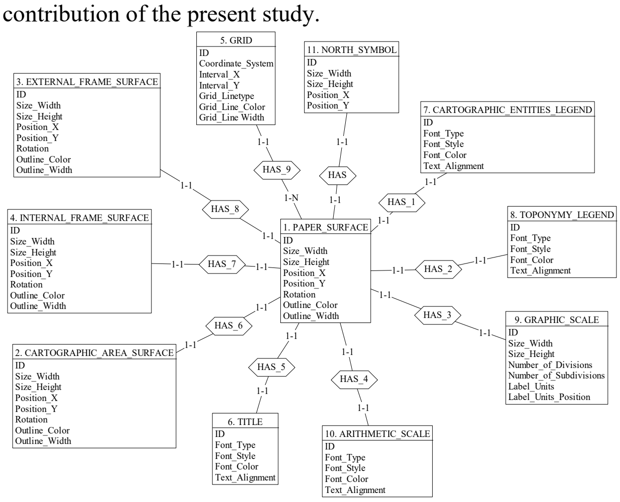


Figure 12: Digital cartographic data and their conceptual model

5. The enrichment of spatial data with their graphical attributes and their use on spatial queries

When using a map, the user seeks specific symbols and/or cartographic entities that represent features of the real world. The colors of these entities have a crucial role in the interpretation and effective use of a topographic map, as well as any other type of map. The colors are related or not with the color/representation of real-life objects e.g. the green for forests and/or green areas in general, or cultivated areas, red for roads or black for railways etc. In any case the colors in topographic maps concern a set of cartographic entities belonging in the same or different classes e.g. green for forests, green for green areas etc., red for urban areas, red for roads, red for buildings, etc. In general, the colors and the graphical attributes, could be used in the frame of cartographic or spatial analysis the same way we use the classes in a classified satellite image. A first attempt on this (classification of paper maps after scanning process) has been done in 2005 (Pantazis et al., 2004a) (Pantazis et al., 2004b) (Karathanassis et al., 2005) (Pantazis et al., 2005) (Pantazis et al., 2007a) (Pantazis et al., 2007b) but for different purposes.

5.1 The use of spatial databases conceptual models to analyse cartographic data

The creation of a spatial database (SDB) as an alphanumerical database follows a number of steps:

a) analysis,
b) conceptual modelling/design,
c) creation of the logical/physical model in a Geographic Information System (GIS) or using a Spatial Database Management System (S-DBMS),
d) data input,
e) errors control,
f) metadata and
g) data dictionary creation.

The use of the conceptual model of a SDB generally ends after its creation. The present work demonstrates that the integrated use of the map and its conceptual model, could improve the formulation and processing of spatial and composite queries within the SDB/digital map (Figure 13).

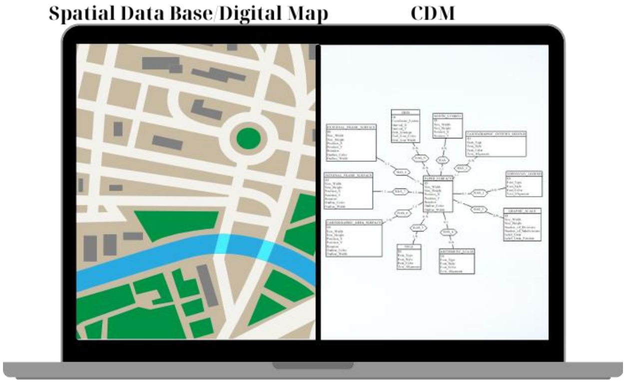


Figure 13: Combined use of a Spatial Data Base and CMD for spatial queries in the frame of our approach.

5.1.1 The use of graphical attributes in spatial queries

A user intending to perform a cartographic analysis may rely not only on the visual information provided by the cartographic data, but also on the associated conceptual model that represents cartographic entities along with their attributes (Figure 14). These include logical attributes (e.g., the types of trees composing a forest) and graphical attributes (e.g., the color assigned to the cartographic entity "forest", such as green).

Unlike standard GIS software such as ArcGIS Pro, which supports queries based primarily on spatial geometry or attribute filters, the proposed approach allows queries that integrate both spatial and graphical attributes as meta-entities. This enables more flexible and semantically-informed map composition and cartographic analysis that cannot be achieved using conventional GIS tools.

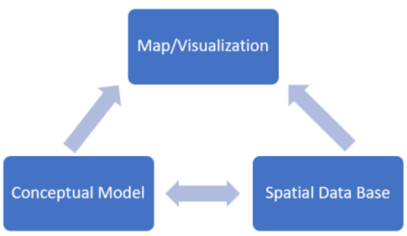


Figure 14: Data and queries/results flow among conceptual model, spatial database, and visualization.

Within the frame of this proposal, spatial requests could combine not only spatial parameters but also graphical ones which may combine or not multiple cartographic entities. E.g. visualization of all green or all red entities (instances) of the spatial database.

Such queries go beyond the classic queries which concern only a type or class of spatial entities (see Figure 15).

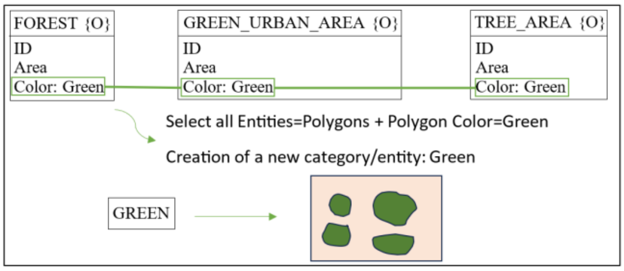


Figure 15: Search of spatial entities with the same color.

With the given GIS tools, there is no direct way to implement this kind of query. The fastest process could be to merge all entities/files that have the same color and then obtain the answer to the question of how many polygons are green. With the proposed method the user will avoid all the above unnecessary steps, gaining time and efficiency.

5.1.2 The use of graphical and logical attributes in spatial queries.

The use of the CDM could facilitate complex requests which combine logical and graphical attributes (Figure 16).

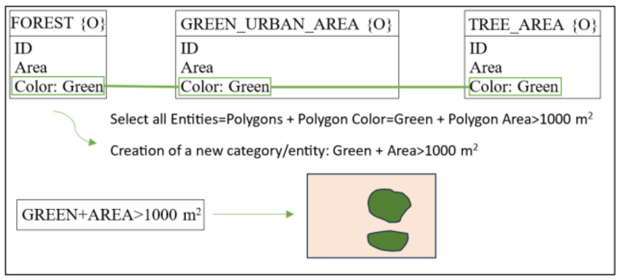


Figure 16: Search of spatial entities with the same color and area greater than 1000 m^2, as implemented using the proposed approach.

As in the case of section 5.1.1, the existent GIS tools cannot answer the above question/query. Also, in this case the fastest process could be to merge all the entities/files that have the same color and then obtain the answer to the question of how many polygons are green. In the new file containing the total of the green polygons a query is executed to extract the polygons that have area greater than 1000 m^2.

With the proposed method the user will avoid all the unnecessary steps.

5.2 Complex request using graphical attributes, logical attributes and topological relationships

The user using the topological relationship table and the CMD could make more complex queries using not only graphical attributes but also logical attributes and topological relationships (Figure 17).

	F	GUA	TreA
F	-	Ap	S
GUA	S	-	Sp
TreA	A	A	-

Figure 17: Topological Model (F=Forest, GUA=Green Urban Areas, TreA=Tree Areas, A Adjacency, Ap Partial Adjacency, S Superposition, Sp Partial Superposition)

The next case that is presented in Figure 18, is the same as the case of section 5.1.2 but now there is one more query. In this more complicated case, the user is interested in identifying not only which green polygons are greater than 1000 m^2, but also from the polygons above which of them have partial adjacency with another polygon (Figure 18).

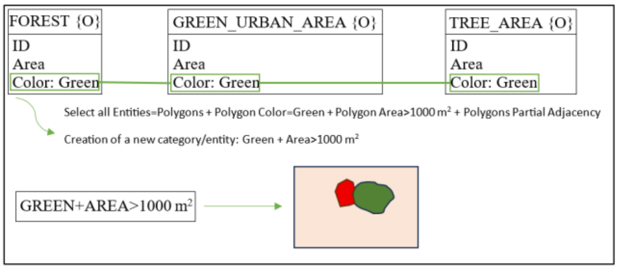


Figure 18: Search of spatial entities with the same color, area greater than 1000 m^2 and the polygons have partial adjacency with another polygon. In this case the red polygon is urban areas.

In this case, the same procedure described in previous sections must be followed. That means that the user should merge all the entities/files that have the same color and then obtain the answer to the question of how many polygons are green. Then in the new file that contains the total of the green polygons will be a query to find which of them have an area greater than 1000 m^2 but also the user will do another query that calculates all the polygons that have partial adjacency.
Within the proposed method, all unnecessary steps are eliminated for the user.

6. Conclusions and perspectives

This research concerns a number of new uses of the CDM. The first meta-model (named meta-model because the map is a model itself) concerns an improved and more user center process for the creation of a map layout/composition. This proposal uses the CDM of a spatial database combined with the digital map as a tool for cartographic and spatial analysis using the graphical and logical attributes of the cartographic entities and their topological relationships. The user can create complex queries with an easy way using the above-mentioned parameters. An efficient implementation of the above proposals could lead to a more intelligent GIS. Although this study reflects an early stage of ongoing research, these proposals present a relevant contribution with adequate scientific grounding for implementation in Python, which is still in progress.
A map includes a lot of information with a complexity that in many cases is not obvious. New tools are necessary in order to explore all its power and value. The proposed approach could contribute to a useful pathway toward achieving this goal. Both techniques make the cartographic data more “intelligent” and the cartographic process easier and less time consuming. Both proposals are in an ongoing process of implementation.

At the same time the new generation of smart GIS should revise the old fashion structure of classes of one type (points, lines or polygons) and the one type objects layers and classes. A transition to a new structure based on CDM, is required to allow the full use of AI, machine learning and big data techniques using: entities of any type, attributes of any entity, and relations (permitted, forbidden, applied totally or partially) between any spatial entity. Last but not least the creation of thematic layers must include all types of spatial entities (points lines, polygons) (Figure 19).

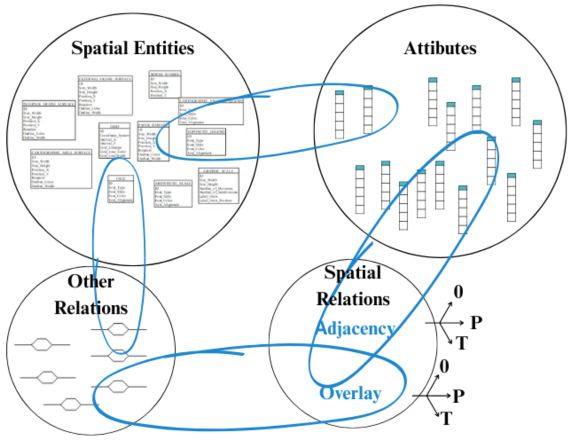


Figure 19: Entities, attributes and relations.

Acknowledgements

The publication/registration fees were partially covered by the University of West Attica

References

Biljecki, F., Ledoux, H., Stoter, J., 2015: Applications of 3D city models: State of the art review. *ISPRS Int. J. Geo-Inf.*, 4(4), 2842–2889. https://doi.org/10.3390/ijgi4042842
Brown, G., Fagerholm, N., 2015: Empirical PPGIS/PGIS mapping of ecosystem services: A review and evaluation. *Ecosyst. Serv.*, 13, 119–133. https://doi.org/10.1016/j.ecoser.2015.02.004
Döner, F., 2021: Analysis of literature on 3D cadastre. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVI-2, 90–97. https://doi.org/10.26833/ijeg.703244
Esri, n.d.: Agriculture Data Model poster. *Esri Data Models – Agriculture*, available at: https://downloads.esri.com/support/datamodels/Agriculture/AGDM_Poster.gif (accessed: 04 April 2025).
Esri, n.d.: Global Map Detail (E-size). *Esri Data Models – Basemap*, available at: https://downloads.esri.com/support/datamodels/Basemap/Global_MapDetail(Esize).pdf (accessed: 06 April 2025).
Esri, n.d.: Historic Preservation and Archaeology Data Model poster. *Esri Data Models – Historic Preservation and Archaeology*, available at: https://downloads.esri.com/support/datamodels/Historic%20Preservation%20and%20Archaeology/HistoricPreservation.gif (accessed: 06 April 2025).
Karathanassis, H., Pantazis, D., Kyriakopoulou, V., Stratakis, P., Yingcheng, L., Guo, T., Rizopoulou, K. (2005). Using classification methods on VHR images for updating middle scales topographic maps, Results of a Two Years Bilateral

Research Project between Greece and China. *Proceedings of the GIS PLANET II International Conference and Exhibition on Geographic Information*, Estoril Congress Center, May 30 – June 2, 2005.

Pantazis, D. N., Mpatsos, E., Poliths, P., Kassolis, M., Stathakis, D., Yingcheng, L., Guo, T. (2007a). Design of multiscale cartographic databases: The Greek case, in Coors, V., Rumor, M., Fendel, E. M., & Zlatanova, S. (Eds.), *Urban and regional data management* (pp. 245-259). Taylor & Francis: London.

Pantazis, D., Mouka, F., Karathanassis, H., Yingcheng, L., Guo, T., Kyriakopoulou, V., Stratakis, P., Karapatsiou, S., Stathakis, D., Santimpantakis, K. (2005). Research of the possibility for accuracy improvement of topographic maps 1:25,000 using high resolution satellite images – Evaluation of results and conclusions in the middle of the project. *Proceedings of the 4th International Symposium on Digital Earth*, Tokyo, Japan, March 28–31, 2005.

Pantazis, D., Panagiotis, E., Yingcheng, L., Guo, T., Karathanassis, H., Stathakis, D., Santimpantakis, C., Stratakis, P., Kyriakopoulou, V. (2007b). Design of (or conceptual modeling) multiscale cartographic databases. *Proceedings of the 26th Urban Data Management Symposium*, Stuttgart, Germany, October 10–12, 2007.

Pantazis, D., Stathakis, D., Yingcheng, L., Guo, T., Karathanassis, H., Karatzalos, K. (2004a). Research of the possibility for accuracy improvement of topographic maps 1:50000 and 1:25000 using high resolution satellite images. *Proceedings of the 7th Global Spatial Data Infrastructure Conference (GSDI)*, Bangalore, India, February 2–4, 2004.

Pantazis, D., Yingcheng, L., Tongying, G., Karathanassis, H., Stathakis, D., Santimpantakis, C. (2004b). The update of topographic maps of middle scales using high resolution satellite images: final conclusions. *Proceedings of the 24th Urban Data Management Symposium (UDMS)*, Chioggia, Italy, October 27–29, 2004.

Yadav, Y., Colucci, E., Boccardo, P., Zlatanova, S., 2024: A geodatabase design for the development of a digital twin for urban environments: A case study from Turin, Italy. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVIII-4, 525–532. https://doi.org/10.5194/isprs-archives-XLVIII-4-2024-525-2024

Yan, J., Jaw, S.W., Van Son, R., Soon, K.H., Schrotter, G., 2018: Three-dimensional data modelling for underground utility network mapping. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-4, 711–715. https://doi.org/10.5194/isprs-archives-XLII-4-711-2018

Yan, J., Zlatanova, S., Aleksandrov, M., Diakité, A. A., Pettit, C., 2019: Integration of 3D objects and terrain for 3D modelling supporting the digital twin. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, IV-4/W8, 147–154. https://doi.org/10.5194/isprs-annals-IV-4-W8-147-2019