# How to Define 3D Geoprocessing Operations for the OGC Web Processing Service (WPS)? Towards a Classification of 3D Operations

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**Abstract.** In the literature a number of taxonomies are present which categorize the functions of GIS. While such taxonomies used to be more of scientific interest they are now getting more practical relevance due to the adoption of the OGC Web Processing Service (WPS) specification. While this standard currently allows specifying arbitrary geoprocessing functionalities, for ensuring interoperability we argue that more detailed definition of possible functions with their parameters is needed. This would facilitate the development of specific application profiles of the WPS if needed. Further classifications of geoprocessing services would help to identify appropriate functions to be grouped together at a higher level (this could be handled in extended web service registries). The goal of this paper is to start a discussion about appropriate concepts of 2.5D (2D with one additional z-value per x-, y-coordinate) and 3D geoprocessing functions and the different ways to group them – in particular we need to distinguish generic and domain-specific functions. This can lead to the definition of relevant WPS profiles. We propose a general classification for 2.5D and 3D functions which contains groups of general purpose functions. This classification leads to sub-classifications that contain several basic functions for each group of the general classification. In addition to these generic functions we further propose domain specific classifications that contain the most important 2.5D and 3D functions for a specific application area, especially functions that are used only within this field. These domain specific classifications will give access to many important functions of a domain. Therefore this paper gives an overview of the state of art, i.e. existing taxonomies of GIS-functions and discusses a new classification for 2.5D and 3D geoprocessing functions as well as domain specific classifications.

**Keywords:** WPS, 3D, geoprocessing, classification.

## 1 Motivation

Geoprocessing is a core functionality of every GIS. In addition to data management and visualization it leverages the real power of GIS through the possibility to conduct

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a vast variety of analysis in an automated and consistent way. Geoprocessing generates new information through the analysis of several data sets and input parameters combining geometrical, topological and semantic aspects.. Geoprocessing has for quite some time mostly been carried out in desktop or workstation environments or through proprietary backbone server systems. Only recently it became also the topic of standardization work within the Open Geospatial Consortium (OGC). The result is the implementation specification recognized as Web Processing Services (WPS) [27]. The idea is that this new OGC Web Service (OWS) shall act as a framework for integrating a variety of geoprocessing algorithms into a service-oriented-architecture (SOA) [e.g. 38]. According to the OGC the WPS "provides client access across a network to pre-programmed calculations and/or computation models that operate on spatially referenced data." [27].

The concept of WPS is quite open and generic. On the one side this allows to use the WPS for basic calculations (e.g. the calculation of a buffer) [15] or diverse aggregation and spatial join calculations [32, 34], accessibility analysis [26], generalization, DEM (Digital Elevation Model e.g. TIN) processing [30], housing market analysis [43] or even geomorphological models [39]. Thus, in principle there are no restrictions on what can be implemented using the WPS interface. On the other side this openness is also the problem because from early versions of the draft up to now there have been complaints, that the "geo" has been neglected within this "geoprocessing" service [32, 15]. Heier [15] works on defining a classification of 2D basic GIS analysis operators based on Map Algebra and other well known 2D geoprocessing functions. This taxonomy defines concepts related to geoprocessing. Based on a common understanding of geoprocessing functions a taxonomy enables the possibility to approach the problem of semantic interoperability [13] of web services through adequate service descriptions [22]. This is an important aspect for the development of future Spatial Data Infrastructures (SDI) built on semantically enriched Web services [2, 19]. Such a classification will enable the development of a Geospatial Semantic Web not only in the sense of finding and visualizing geoinformation, but also on geoprocessing data.

To enable users to identify 2.5D and 3D geoprocessing functions and to convey the development of a Geospatial Semantic web, a classification for general purpose 2.5D and 3D functions and classifications for specific domains are required. The aim of this paper is to present possible structures and typologies that can be applied to the concepts within 3D geoprocessing. Therefore we give an overview about existing taxonomies of GIS functions (not only in 3D and regarding geoprocessing) and identify their similarities or differences in chapter 2. In chapter 3 we propose 2.5D and 3D geoprocessing functions for a general WPS profile and discuss the suitability of existing taxonomies as a foundation for a classification for 3D geoprocessing algorithms. Proposals for such a general WPS classification are discussed in chapter 4 and functions for a sub-classification for one of the groups of the general classification as well as a domain specific profile are discussed in chapter 5.

## 2 Related Work

An appropriate classification should have the following characteristics: It should be able to assign every function to exclusively one class, which means that it should be consistent. The general classification should be independent of the underlying data structure, so that it has the capability to be as universal as achievable. It should be possible to integrate new functions.

There exist many possibilities to group GIS functions, whereas not all groupings were created as general purpose classifications or taxonomies. We start with very fundamental classifications that order functions along the data flow from input through processing to output. This is not yet specific to our focus on 2.5D and 3D functions, but helps us to get an idea of the broader picture: Maguire and Dangermond [23] identified ten major categories of GIS functions of a typical GIS project: capture, transfer, validate and edit, store and structure, restructure, generalize, transform, query, analyze and present. A similar list of GIS functions present Rhind and Green [29]: Data input and encoding (capture, validation and storage), data manipulation (conversion, generalization, classification, enhancement and abstraction), data retrieval, data analysis (spatial, statistical and measurement), data display (graphic and report writing) and database management. These lists present important functions and are independent of data structure, but they include also functions which cannot be categorized as geoprocessing and some functions could be grouped to more than one category. Further we need to select the subset relevant for 3D geoprocessing.

Tomlin [37] groups data processing activities into programming, data preparation, data presentation and data interpretation by the communication paths between input and output devices, the processing unit and the storage facilities. Data interpretation operations are further categorized into operations on individual locations, locations within neighborhoods and locations within zones. This ensemble is also called Map Algebra and the categories are also called local, focal and zonal functions. This classification is mostly concerned with raster calculations. Many possibilities of vector geometries are neglected. The Map Algebra functions are implemented in many Geographic Information Systems. They are also extended in many ways e.g. to functions which are concerned with vector fields [20], 2D data and time [25], 3D voxel data [31] and a combination of time and 2D / 3D data [24].

A classification of operations that is based on layers was developed by Hadzilacos [12]. This classification consists of four categories: derive computable attribute, compute spatial (geometric operations based on one layer), reclassification and overlaying. This classification does not consider functions for objects.

Goodchild [11] distinguishes six classes of spatial analysis operations. It is differentiated whether attributes or locational information or both are used for the analysis and whether only one or more object classes are required. An additional class is established which creates a new object class from existing objects. A special feature of this classification is the explicit consideration of creation and analysis of object pairs. This classification concentrates on objects and does not consider some functions of the (extended) Map Algebra.

Burrough [3] gives nine classes of how new attribute values and new objects can be created. In the first and second class new attributes are created of attributes of exact and non-exact values. Creation of new values from attributes of neighborhoods of discrete objects and fields are divided into classes three and four. Functions that create new values for new attributes of neighborhoods build class five. When new objects are created or modified the functions belong into class six. Class seven functions create new attributes through measurements and analysis of topological relations. Creation of reports belongs to class eight and data management operations into class nine. These classes also include functions which cannot be classified as geoprocessing functions. There are also different classes for objects and fields, so that the same function for different data structures can fall into different classes.

Albrecht [1] created a classification of functions from the user's perspective and defined 20 universal task-oriented GIS-operations. These 2D and 2.5D-operations are grouped into interpolation, search, locational analysis, terrain analysis, distribution and neighborhood, spatial analysis and measurements (see Table 1). Preparatory and data-oriented functions are not included in this list.

**Table 1.** Albrecht's Universal GIS-Operations [1]

| | |
|---|---|
| Search | interpolation, search-by-region, search-by-attribute, (re-)classification |
| Locational Analysis | buffer, corridor, overlay, Voronoi/Thiessen |
| Terrain Analysis | slope/aspect, catchment/basins, drainage/network, viewshed |
| Distribution / Neighborhood | cost/diffusion/spread, proximity nearest-neighbor |
| Spatial Analysis | multivariate analysis, pattern/dispersion, centrality/connectedness, shape |
| Measurements | measurements |

Chrisman [4] defines a taxonomy based on the nature of the transformation. The four cases are: transformation by extraction, based on attribute rules, with geometric processing only and complete transformation. These categories consider how data are transformed and whether it is possible to reverse the transformation. The classification is mostly concerned with surfaces and pays less attention to objects.

Giordano et al. [10] ordered functions into the basic processing steps of a GIS project: input, analysis and output. Within each of these groups functions are ordered according to their impact on uncertainty. Input includes restructuring, compilation as well as editing and output includes restructuring, reporting and visualization. The taxonomy focused on the analysis functions; therefore this group entails most functions. The six groups are logical, arithmetic, overlay, geometric property, geometric transformation and geometric derivation operations. This taxonomy is more applicable to raster than vector GIS, as some vector GIS functions do not fit in the taxonomy.

Egenhofer and Herring [7] categorize spatial relations with the fundamental mathematical concepts topology, order and algebra. Topological relationships are invariant under topological transformations. Spatial order relations, such as above, below, in front and behind can be grouped in order and strict order. Metric relations are distance and direction. Only the topological relations are further investigated in this paper. Topological relationships can be classified using the 9-intersections model where the relationships of the two simple objects A and B with their boundary, interior and exterior are considered [7, 8]. This model can describe any possible relationship and any constellation between two objects is defined by exactly one relationship. Theoretically this 9-intersections model leads to 512 ($2^9$) relationships with empty or nonempty value but not all relationships are possible. Zlatanova [40, 41] presents an approach to eliminate impossible relationships. For example the Body-Body relationships in three dimensional space can be reduced to eight possibilities. The model is sophisticated e.g. by taking into account the dimensions of the intersections or by allowing more sophisticated objects like regions with holes [6].

With respect to existing standards the ISO Standard 19107 is concerned about vector data up to three dimensions (solids). It specifies also a range of basic geoprocessing functions that are presented with the objects on which they are applicable. These operations include such simple functions as creating a centroid or buffer to more complex topological functions such as functions after the 9-intersections model [16]. The functions are presented one after another without an immanent order.

Raper [28] classifies 3D spatial query and analysis functions into Visualization (Translate, Rotate, Scale, Reflect), Transformation (Sheer), Selection (AND, OR, XOR, NOT), Interrelationships (Metric, Topological), Characterization (Volume, Surface area, Centre of mass, Orientation) and Modeling (Build). This classification covers also functions which are usually not classified as geoprocessing functions in the stricter sense. As it focuses on analytic geoprocessing functions it would need extensions for other types of geoprocessing functions.

Kim et al. [18] focus on 3D geographic analysis and classify functions based on their functionality into geometric analysis, spatiorelational analysis and geometry-generating analysis. As they only focus on analysis, this classification would need extensions to cover other functions.

The presented taxonomies were all created for a particular area of application and fulfill their intended purpose. We try to identify their common characteristics with respect to 2.5D and 3D geoprocessing functions. These are presented in the next sections. These can be used to examine how a taxonomy for classifying 2.5D and 3D geoprocessing functions might look like.

## 3 A Proposal of General 2.5D and 3D Geoprocessing Functions

In the following section a number of typical groups of 2.5D and 3D geoprocessing functions are presented. It is not possible to present all possible functions, so in the literature frequently named groups of functions are offered. Then the functions are assigned to the most applicable category of the data model independent classifications. Each number in the matrix stands for the corresponding function from the operations lists. A number in bracket means that the function does not match the category exactly.

### Typical 2.5D Operations on DEM with 2D and 2.5D Objects

1. **Interpolation:** create a DEM (TIN or raster) from raw data. This group could give access to multiple interpolation functions and arithmetic operations
2. **Manipulate DEM:** features can be added or erased from a TIN. Additional data for interpolation can be included for raster and assembly and tiling of DEM
3. **Dimensional Transformation:** creates 2.5D objects from 2D objects and vice versa; it also extracts nodes of objects
4. **Data Conversion:** converts a data model and format e.g. TIN - raster or DEM into objects; incl. creation of contour lines

5. **Validity Checking:** test validity of geometry and topology of features and DEM
6. **Generalization:** erase details as well as create and adjust Level of Detail (LOD)
7. **DEM Characterization:** calculates slope, aspect, curvature and surface area
8. **Visibility:** calculates visibility of objects on DEM and of surface from objects
9. **Distance and Angle:** different distances like centroid, minimum and maximum distance as well as angles between objects can be calculated
10. **Length and Perimeter:** of objects can be calculated
11. **Volume and Area Difference**: between two DEMs, or one DEM and objects
12. **Watershed:** calculation of watersheds and delineation of catchment areas
13. **Illumination Analysis:** e.g. creation of hillshade
14. **Profile:** creates a graph that shows elevation changes of a DEM along a line
15. **Buffer:** gives access to several buffer creation methods
16. **Topological Analysis:** using the 9-intersection model and extensions
17. **Network Analysis:** e.g. routing over DEM (e.g. including height differences & steepness) and locating next object
18. **Geostatistic:** including min, max, local min and local max

### Typical 3D Operations on 3D Objects and Combinations with DEM

1. **Interpolation:** e.g. to create new objects, arithmetic and logical operations, intersection and fitting of objects
2. **Dimensional Transformation:** setting 2D objects to a base height and extruding objects as well as extracting footprints and nodes
3. **Data Conversion:** converts data model and format
4. **Validity Checking:** tests validity of geometry and topology of features

**Table 2.** Matrix of DEM functions per relevant category based on selected authors

| ***Maguire / Dangermond*** | ***Rhind / Green*** | ***Albrecht*** | ***Raper*** | ***Kim et al.*** |
|---|---|---|---|---|
| Capture, transfer, validate and edit: (2), 5 | Data input and encoding: 3, 5 | Search | Visualization | Geometric analysis: 7, 10, 14, 12, 17 |
| Store and structure | Data manipulation: 3, 4, 6 | Locational analysis: 15 | Transformation | Spatio-relational analysis: 8, 9, 11, 13, 16 |
| Restructure, generalize and transform: (3), 4, 6 | Data retrieval: | Terrain analysis: 7, 8 ,12, 13, 14, (17) | Characterization: 7, (10), (13), (14), (15) | Geometry-generating analysis: (1), (2), (3), 15 |
| Query and analyse: 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 | Data analysis: 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 | Distribution / neighborhood: 9 | Inter-relationships: (8), 9, (11), (15) | |
| Present | Data display | Spatial analysis: 16 | Section | |
| | Database management | Measurements: 10, 11 | Modeling: 1, (2), (3) | |
| Not applicable / fall into more than one category: | | | | |
| 1 | 1, 2 | 1, 2, 3, 4, 5, 6 | 4, 5, 6, 9, 12, 17 | 4, 5, 6 |

5. **Generalization:** erase details as well as create and adjust Level of Detail (LOD)
6. **Orientation:** absolute orientation (aspect in real 3D) and relative orientation (above, below, in front, behind and angle)
7. **Visibility:** including total and percental visibility of objects
8. **Distance and Angle:** different distances like centroid, minimum and maximum distance as well as angles between objects can be calculated
9. **Object Characterization:** calculates length (of line over 3D objects and perimeter), surface area, volume, height, center of mass, form of objects (convex, concave etc.)
10. **Illumination Analysis:** e.g. shade, shadow and insulation
11. **Profile and Section**: creates a graph that shows elevation changes along 3D objects as well block diagrams
12. **Buffer:** gives access to several buffer creation methods
13. **Topological Analysis:** using the 9-intersection model and extensions
14. **Network Analysis:** Network analysis on 3D objects
15. **Geostatistic:** including min, max, local min and max in 3D

The tables two and three demonstrate that either most functions fall into one category of a classification or a lot of functions cannot be applied to a category. In the case of the categorizations along the data flow of a GIS project most functions fall into the category query and analyse or data analysis respectively. Many other categories stay empty. All other categorizations are not able to assign each operation to one category. This is not a surprise, since these taxonomies were created for a different purpose.

**Table 3.** Matrix of 3D functions per relevant category based on selected authors

| ***Maguire / Dangermond*** | ***Rhind / Green*** | ***Albrecht*** | ***Raper*** | ***Kim et al.*** |
|---|---|---|---|---|
| Capture, transfer, validate and edit: 4 | Data input and encoding: 4 | Search: (1) | Visualization: | Geometric analysis: 6, 9 |
| Store and structure | Data manipulation: 2, 3, 5 | Locational analysis: 12 | Transformation | Spatio-relational analysis: 7, 8, 10, 11, 13 |
| Restructure, generalize and transform: (1), (2), 3, 5 | Data retrieval | Terrain analysis: (6), (7), (11) | Characterization: 6, 9 | Geometry-generating analysis: 1, (2), 12 |
| Query and analyse: 6, 7, 8, 9, 10, 11, 12, 13, 14 | Data analysis: 6, 7, 8, 9, 10, 11, 12, 13, 14 | Distribution / neighborhood: 8 | Inter-relationships: (7), 8, (10), (11) | |
| Present | Data display | Spatial analysis: 16, 17, (10), 13, 14 | Section | |
| | Database management | Measurements: 9 | Modeling: (2) | |
| Not applicable / fall into more than one category: | | | | |
| | 1 | 2, 4, 5 | 1, 3, 4, 5, 12, 13, 14 | 3, 4, 5, 14 |

Most taxonomies were created to handle 2D operations and operations on 2.5D-data (2D data with one additional z-value per x-, y-coordinate). It is possible to extend these taxonomies to cover 2.5D and 3D; such as Tomlin's Map Algebra was already extended into the third dimension. But the focus of these taxonomies still remains on the original purpose. For instance the extended Map Algebra focuses on raster data whereas a classification of WPS functions shall cover raster and vector functions.

While some categorize all GIS functions, many taxonomies concentrate on analytical functions. The focus of geoprocessing is in between, because it includes all analytical functions, but not all GIS functions e.g. no pure data preparation and visualization. A taxonomy that can act as the basis for creating a WPS classification for generic geoprocessing functions needs to be able to assign every function to exactly one class.

An important distinction between the classifications is whether they are made more from a user's point of view or the data processing view. Albrecht's classification is explicitly made from the user's point of view, as are the classifications that group the functions along the data flow of a GIS-project. On the other hand the analysis functions in Tomlin's Map Algebra are ordered according to the data foundation. We argue that a classification for general WPS functions should present in particular the users point of view, so that it will assist the user to find an appropriate function, but this is not the only aspect that will be covered.

## 4 Towards a 3D Classification for Geoprocessing Operations

In this section a classification is presented which groups geoprocessing functions and helps to get an idea of possible applications. This classification is independent from the data model and besides integrating domain independent functions it is open enough to integrate domain specific functions also. The classification takes explicitly the dimension into account, because the dimension of the data determines which functions are applicable and which outcomes can be expected. Therefore the classification is divided into 2.5D functions (which run mainly on a DEM) and real 3D functions. A lot of 2.5D functions are already available in commercial GIS, whereas most of real 3D functions are not implemented into commercial systems yet. Some functions are applicable for 2.5D and 3D data and are therefore listed in both categories. These two categories are subdivided into Creation and Conversion, Geometric Analysis, Topological Analysis and Mixed Analysis functions. These categories are relatively straightforward because they determine on which data basis the function will run – on attributes, geometry, topology or on a combination of them. All functions from chapter three are assigned to the appropriate category.

**Operations on DEM with 2 and 2.5D Objects**

**Creation and Transformation**
Interpolation, Manipulate DEM, Dimensional Transformation, Data Conversion, Validity Checking, Generalization

**Geometric Analysis**
DEM Characterization, Visibility, Distance and Angle, Length and Perimeter, Volume and Area Difference, Watershed, Illumination Analysis, Profile, Buffer

**Topological Analysis**
Topological Analysis derived from the 9-intersection model

**Mixed Analysis**
Network Analysis, Geostatistic

**Operations on 3D Objects and Combinations with DEM**

**Creation and Transformation**
Interpolation, Dimensional Transformation, Data Conversion, Validity Checking, Generalization

**Geometric Analysis**
Orientation, Visibility, Distance and Angle, Object Characterization, Illumination Analysis, Profile and Section, Buffer

**Topological Analysis**
Topological Analysis derived from the 9-intersection model

**Mixed Analysis**
Geostatistic, Network Analysis on 3D objects

## 5 Basic Functions Versus Domain Dependent Functions

The groups of functions from the general 2.5 and 3D WPS classification can be further subdivided into basic geoprocessing operations or algorithms that actually perform the processing steps. Some functions will perform a specific task on their own, while for other tasks it will be necessary to combine some functions which are eventually in turn hierarchically ordered.

Besides general purpose functions there exist domain specific functions, which could be grouped together with general purpose functions that are used within that domain into domain specific profiles. This would ease to access frequently used functions of a certain domain. For example the functions defined by Wood [39] can be seen as a set of domain specific geomorphological geoprocessing functions, that can act as a basis for a specific landscape analysis classification. In this chapter we present 3D geoprocessing functions that are relevant for urban planning.

### 5.1 Incorporating Basic Geoprocessing Functions: Example TIN Generalization

The general 2.5 and 3D functions discussed above are more or less independent from a data model, but the actual basic geoprocessing operations realizing these functions are mostly only applicable for a specific data model. A further challenge is to choose a specific function or algorithm, because the choice depends on the actual aim and has to deal with several tradeoffs. A typical tradeoff exists between fast operations on the one hand and accurate functions on the other hand. In the following basic geoprocessing functions are presented in order to illustrate the step from general function groups to basic geoprocessing functions. As mentioned earlier, most basic functions depend on the data model. As an example this section will focus on generalizing functions for

TINs. These functions could be part of a basic “(DEM) Generalization” function group.

There are many reasons for generalizing TINs like speeding display, printing and computation, reducing redundancy, removing unnecessary details, for aesthetic reasons, save disk space and reducing transmitting time. Then again generalizing functions have to fulfill certain constraints, as maintaining topology, visual appearance, geometric characteristics, maximum error, and maximum processing time. Some functions work well for slight date reductions and others for considerable reductions [5]. As every discipline has their own set of requirements and constraints there is no single all purpose function. On this account Heckbert and Garland detected dozens of surface simplification functions in the literature [14].

Most generalizing functions for TINs have five elements in common. First, there is some algorithm that determines which features (vertices, edges, and triangles) qualify for elimination or have to be added. Second, there has to be a function to calculate the error for eliminating or adding a feature. This part is sometimes combined with the first one. Third, the calculated error has to be compared to a previously defined threshold. Fourth, there has to be an algorithm to eliminate or add a feature and fifth there has to be an algorithm for (re-) triangulation. For every part there exists a wide variety of functions.

There exist a lot of possibilities to determin which features qualify for elimination or have to be addet. Identifying coplanar or nearly coplanar faces, edges that fulfill a near or angle measure or fulfill some topological criterion (vertices connected by edge, not on boundary, not on breakline etc.) are frequently mentioned. Error calculation can be done by measuring distance, minimizing an “energy function”, computing error quadrics [9] etc. The quality threshold can either be applied locally and a feature deleted or not or a global ranking can be applied and only as many features are deleted that some maximum TIN size is met.

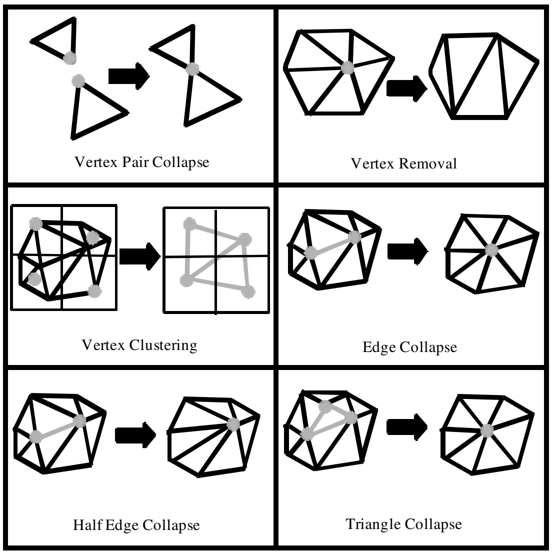


**Fig. 1.** TIN feature elimination functions

Some functions for feature elimination are vertex pair collapse, vertex removal, vertex clustering (also named cell collapse [21]), edge collapse, half edge collapse, and triangle collapse (fig 1). Delaunay triangulation is the commonly used triangulation function but also other functions exist that may yield better results for specific applications.

A basic TIN generalization function could take the following input parameter: *InputGeometry* (geometry to generalize), *FeatureElimination* (designated function for feature elimination as stated above) and *MaxError* (maximum error in meter). This function could be registered on a basic “Generalize” classification and provided as a WPS process which can be called by a Key Value Pair (KVP) encoded WPS *Execute* request. This request would look like this:

```
http://localhost:8080/wps?
request=Execute&
service=WPS&
version=1.0&
Identifier=TINgeneralization&
DataInputs=InputGeometry,
http://localhost:8080/mytin.gml,
FeatureElimination, VertexPairCollapse, MaxError, 1
```

The WPS (according to the version 1.0 of the specification) process *TINgeneralization* is requested with an input TIN named mytin, encoded in GML (Geography Markup Language) and stored on a web accessible resource. The feature elimination function will be vertex pair collapse and maximum error will be 1 m.

### 5.2 Domain Specific Classifications: 3D City Model Analysis for Urban Planning

Besides the general geoprocessing functions also domain specific functions could be provided by WPS. To order these functions domain specific WPS classifications could be constructed. These classifications should include relevant functions for a domain. This could also include functions from the general classifications. It follows from this that in that case some functions could belong into several profiles. In the following section we present a proposal of a high-level WPS-profile for analysis of 3D city models for urban planning as an example for a domain specific grouping of 3D analysis functions.

An increasing number of local authorities build up 3D city models. Most of them are used mainly to improve planning processes. The three dimensional visual impression is an important assistance for planners and the public, but analysis of the generated data can benefit the planning process in many ways.

This proposed WPS profile presents operations that are already used or urgently needed in planning processes using 3D city models. The majority of the functions turns out to be rather complex. Some may use several more basic DEM functions as explained above, but in most cases special domain specific external algorithms are being used. Due to the diversity of the used algorithms we present only the broad categories. The definition of the actual parameters and data sources needed for each of these functions is out of the scope of this paper. We identify the following function groups as important building blocks for a 3D urban planning WPS profile:

**3D Geoprocessing Functions Relevant for Urban Planning:**

**Containment spread:** Analysis of exposure to particulate matter from traffic and other sources.
**Noise modeling:** Analysis of exposure to street noise and other noise sources.
**Wind simulation:** Simulation of airstreams to support windmill positioning and to calculate modification of airstreams through new constructions.

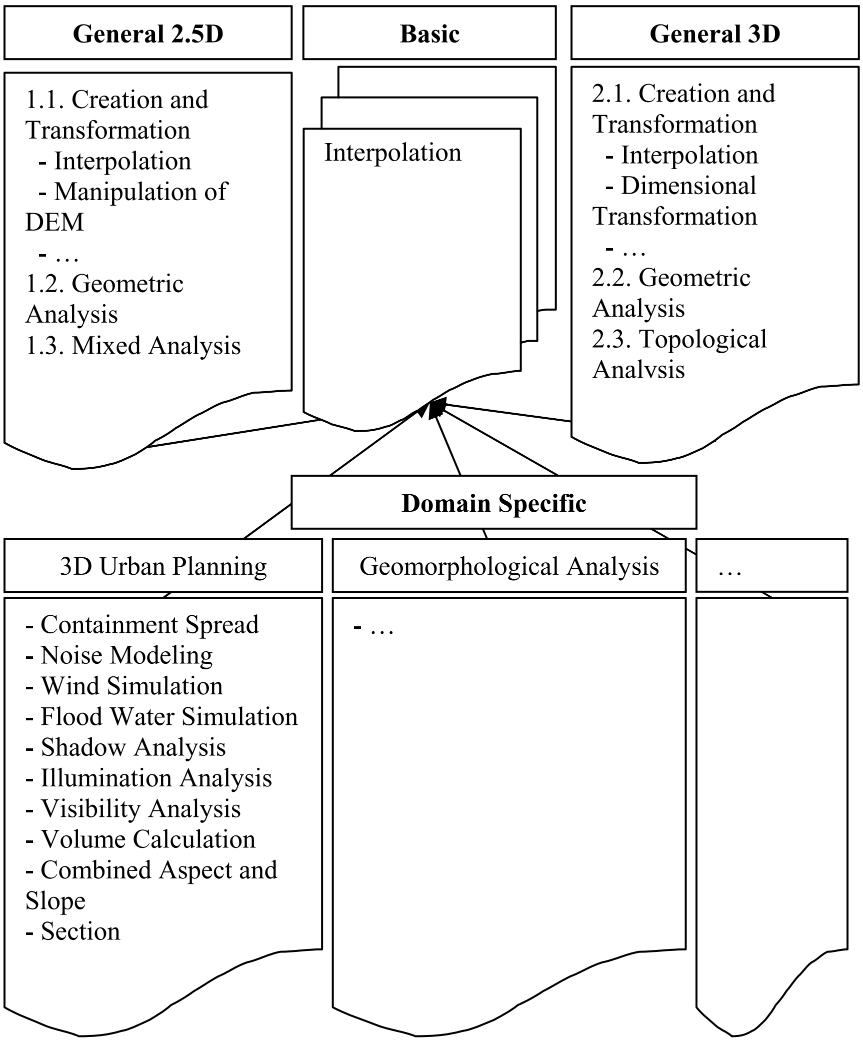


**Fig. 2.** Relationship of Classifications

**Flood water simulation:** Simulation of flood water over & underground and effects of flood control measures.

**Shadow analysis:** This will calculate the shading through new constructions on the neighborhood.

**Illumination analysis:** With this function optimal placement of street lamps can be determined.

**Visibility analysis:** Calculation of visibility of objects and creation of difference maps before and after a proposed construction.

**Volume calculation:** Calculation of construction volumes.

**Combined aspect and slope:** Aspect and slope for DEM and real 3D objects to support evaluation roofs for solar panel placement.

**Section:** Sections with real 3D objects can help to evaluate locations of highrise buildings.

### 5.3 Relationship of Classifications

The general 2.5D and 3D WPS classifications contain groups of functions which lead to sub-classifications that contain the actual functions which can be executed. Additional domain specific classifications contain functions that are applicable especially in that special field. The same function from a domain specific classification can appear on several classifications. Functions from domain specific classifications can be linked to functions from basic classifications (fig. 2).

## 6 Conclusions and Further Work

The WPC specification is now an official implementation specification of the OGC. Furthermore first specification conformal processes are implemented and published. There is an urgent need to establish a classification of these functions that will enable users to find demanded processes.

In this article we give an overview of existing classifications and taxonomies of GIS functions and propose function groups of 2.5D and 3D GIS functions. Further we examine the suitability of selected classifications for 2.5D and 3D geoprocessing functions. Existing classifications concentrate mostly on 2D functions, not all of them on geoprocessing. Therefore we propose a different classification that distinguishes functions based on the dimension (2.5D and 3D) of the data input and four categories (Creation and Conversion, Geometric Analysis, Topological Analysis and Mixed Analysis).

Further we concretize a sub-profile for the 2.5D Generalization function group as well as a domain specific classification and give details about the relationship of general function groups, basic functions and domain specific classifications.

Due to the limited space only a first introduction and some examples of possible classifications could be discussed. Of course there are a range of open issues we did not discuss, including aspects such as time, fuzziness, error measurement etc. More detailed discussions on individual sub-classifications are needed, both related to domain-specific processes, as well as such for specific data models. But the proposed classifications for general geoprocessing functions for both 2.5D as well as 3D give a framework for further analysis. We believe that we have identified the most important categories within 2.5D and 3D geoprocessing as a first step. Future work is needed to derive further relevant domain-specific WPS functions classifications from these, which then can act as input for WPS profiles or new mechanisms of grouping WPS geoprocessing functionalities technically.

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