On Problems and Benefits of 3D Topology on Under-Specified Geometries in Geomorphology

Marc-O. Löwner

Abstract The science of geomorphology is working on natural 3D landforms. This includes the change of landforms as well as the processes causing these changes. The main concepts of geomorphology, i.e. the sediment budget and the sediment cascade approach can definitely be enhanced by introducing 3D geometrical and topological specifications of the Open Geospatial Consortium. The ISO 19107, Spatial Schema, implements OGC's Abstract Specification. It enables the modelling of real world 3D phenomena to represent them as formal information models. Unfortunately, OGC's concepts are not widely applied in the science of geomorphology. In this article we are going to show the explicit benefit of 3D topology for the science of geomorphology. Analysing topological relationships of landforms can be directly related to geomorphic insights. This includes firstly, the process-related accessibility of landforms and therefore material properties, and secondly, the chronological order of landform creation. Further, a simple approach is proposed to use the benefits of the abstract specification 3D topologic model, when only *under-specified geometries* are available. Often, no sufficient data is available on natural landforms to model valid 3D solids. Following clearly defined geometric conditions the introduced class `_UG_Solid` mediates between primitives of lower dimension and a `GM_Solid`. The latter is the *realisation* of a `_UG_Solid` that definitely holds the 3D geometry we need to associate with the 3D topological concepts.

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1 Introduction and Problem Statement

The Open Geospatial Consortium's Abstract Specifications (OGC 2012) enable the modelling of real world phenomenon to represent them as formal information models (Kottman and Reed 2009). These information models may include geometry, attributes and topological relationships of real world objects. The main advantage of international accepted standards like OGC' Abstract Specification is interoperability. This means the seamless exchange of data and a simplified application of analysis concepts. The main document presenting the Abstract Specification is the ISO 19107 'Spatial Schema' (Herring 2001) defining geometric primitives and complexes from 0D to 3D according to the boundary representation (Foley et al. 1995). Next to other concepts, Spatial Schema is implemented in the Geography Markup Language (GML) (Lake et al. 2004). The release of GML led to a number of application schemas e.g. City Geography Markup Language (CityGML) (Gröger et al. 2012). However, CityGML mainly represents models on manmade environments.

Spatial Schema also provides a topology package mainly to convert computational geometry algorithms into combinatorial ones (Herring 2001, p. 104). Topological primitives (i.e. node, edges, faces and solids) need realizations in the form of geometric primitives with the same dimension. Thus, if no valid 3D geometry is provided for features that are known to be 3 dimensional, no 3D topology can be applied.

In the science of the land's surface, geomorphology, objects under examination are definitely volumetric. Built of sediment that is allocated by mainly externally driven processes geometry concepts of the Spatial Schema would be helpful to resent such sediment storages. Topological concepts may support the analysis of geomorphic systems in two aspects. Firstly, identifying neighbouring features and features connected via material transporting processes and, secondly, supporting analysis of landform's chronological order within a geomorphic system.

However, OGC's 3D concepts are not widely accepted in geomorphology. This is different with the simple feature concept implemented by main GIS companies. The main reason is that 3D data is difficult to collect due to complex phenomena and limited prospecting methods. Thus, especially 3D topology is not applicable to the science of geomorphology, since the topology package of Spatial Schema needs to refer to a valid geometry representation.

In this article a new class for 3D objects with under-specified geometry is proposed. _UG_Solid mediates between Spatial Schema's geometric primitives with a dimension less than 3 on the one side and a GM_Solid on the other. Constraints to aggregate a _UG_Solid are defined. The introduction of _UG_Solid enables the application of 3D topological concepts to geometric objects that are known to be volumetric but have to be constructed from sparse data.

In the next section the nature and main concepts of geomorphology will be outlined. A special focus is put on the topological aspects of landforms. Special cases of topological relationships between 3D solids will directly be related to geomorphic insights (Sect. 2.2). In Sect. 3 an application model on geomorphic objects and processes will be reviewed. Data acquisition and modelling problems have been identified as the main problems for the acceptance of 3D concepts (Sect. 3.3). Section 4 focuses on utilization the 3D topological concepts. Constraints for building an under-specified 3D geometry will be defined and proven for geomorphology. Section 5 follows up with a discussion.

2 Geomorphology: The Science of Natural 3D Landforms—Geometrical and Topological Considerations

Geomorphology defines itself as the science of natural landforms (Chorley et al. 1984; Hugget 2003). This does not only include geometric aspects of a 2.5D land surface which are covered by the science of geomorphometry in detail (Evans 1972; Rasemann 2004), but the change of landforms and the processes causing these changes. In general, landforms can be described as units of material, the sediment, which was accumulated under specific conditions and is reworked due to shape, material properties and external forces. The outcrops of these landforms compose the 2.5D boundary surface between solid earth and the atmosphere and the hydrosphere.

Without doubt, climate and gravity are the main external forces of such material transport processes (e.g. soil erosion and the corresponding accumulation or mass movements). In the first place running water erodes and transports material from one landform and accumulates it on the top of another one. Next to climate conditions the eroding power of flowing water is determined by the surface (e.g. slope) and the material's resistance. The same internal properties (e.g. soil texture or bulk density) determine the effectiveness of gravity causing mass movements like rock fall or debris flows (Summerfield 1997). The latter is definitely a property of a 3-dimensional body holding the sediment of a landform. Therefore, in geomorphology the *surface* under consideration is a three-dimensional body divided into neighbouring landforms. These facts are expressed in the broadly accepted term *georelief* coined by the German scientists Kugler (1974) and Dikau (1996). First, it represents the visible and measurable boundary surface between land surface and atmosphere or hydrosphere and, second, the material this surface is composed of (Young 1978). In geomorphology this recognition results in a triad of process, material and form. These three variables are characterised by strong feedback which has to be resolved when describing a geomorphic system.

It is obvious that a 2.5D concept is not sufficient to represent the 3D georelief under investigation. While geomorphology investigates the history of landforms, next to the visible surface, the subsurface is of interest as well. This subsurface, the paleo-surface, forms the starting conditions of the landform under investigation and therefore an important jigsaw piece revealing the landform's history. Anyway, a 2.5D concept is not able to represent more than one surface at a given position.

2.1 On Main Concepts of Geomorphology

Sediment budgets in geomorphology are used to quantify erosion and accumulation processes on a catchment scale. They are expressed by the sediment-delivery ratio. This describes the ratio between sediment eroded and transported in and through a system and material finally pushed out of the system (Cooke and Doornkamp 1990; Reid and Dunne 1996). Thus, sources and sinks of a geomorphic system have to be investigated and quantified. Performed by ground openings, drillings or geophysical exploration, geometry and thus volume of sediment bodies are reconstructed. Internal properties of investigated sediment bodies give hints to the main material transport processes and the periods in which these processes were active. The main material transport process might change in time due to climate variation and others.

The sediment budget concept in geomorphology may definitely be enhanced by the 3D modelling concepts of the Spatial Schema. The approach investigates true 3D geometries to get volumetric information. Application models are needed to store internal properties of the objects under investigation (i.e. soil type, density, chemical composition, etc.). Representing a geomorphic system in an application model would further support the exchange of data within and throughout the community.

The concept of a *sediment cascade* expands the sediment budget approach to the detailed questions concerning residence time of sediment. It is one of the main concepts in geomorphology (Church and Slaymaker 1989; Jordan and Slaymaker 1991). In theory, sediment is captured in storages for a certain length of time. This length depends on eroding processes, their force and, of course, the sediment's internal resistance to these processes. In terms of system theory (Chorley and Kennedy 1971), the output of one storage acts as the input for another one. Regulators like the land surface may divide the eroded material either to stay on the landform or to be transported to one or many others.

One example of a sediment cascade is the interaction of a free face, i.e. a wall, with an underlying talus slope (rf. Fig. 1). As the main storage, the wall feeds the talus slope by stone fall. The talus slope is situated at the walls foot and built up of wasting products of the wall. Nevertheless, the same process could accumulate the material on smaller features sitting on the wall itself, i.e. a band or a cleft. While a band is a step like feature a cleft is a crack present in every wall. Both are able to store material. Due to the formalism used in geomorphology (rf. Schrott et al. 2003), no geometry or time is represented.

While material exchange is more likely to be found between adjacent landforms, topological representation and analysis could definitely support the concept of a sediment cascade in geomorphology. Even the chronological order of landform creation can be analysed using topology (see below). Representing a sediment cascade following the concepts of the Spatial Schema would enable such investigations.

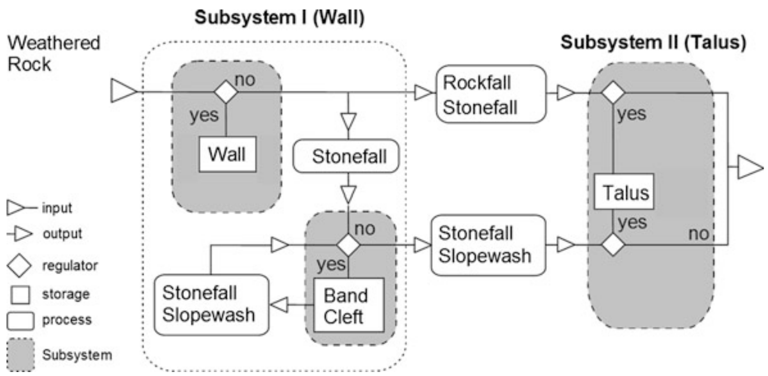


Fig. 1 Sediment cascade of the two subsystems Wall and Talus. Following the notation of system theory, no geometry and time is represented

2.2 Topological Aspects of Landforms

Landforms do not exist in isolation but do interact with others. Their specific association builds up the *georelief* (Kugler 1974; Dikau 1996) and characterizes a specific geomorphic system. While single landforms are scale-dependent, the composition of a geomorphic system follows a spatial hierarchy (Ahnert 1988; Dikau 1989; Brunsden 1996). Smaller landforms are located on the top of larger ones and cover them partly. Therefore, size is a good indicator of a landform's lifetime and age (Ahnert 1996).

Like a single landform, the association of many depends on internal system states, material supply and external driving forces. Following this experience, analysing the composition of landform association allows scientists to understand the main processes reworking a system, the succession of these processes in the past and probable developments in the future.

A lot of the landform's interaction may be analysed using the concept of topology. First, this includes the chance of processes to transport material from one landform to another one. Identifying possible material sources is the first step to expose and explain existing sediment cascades of a geomorphic system. Second, topological investigation may help to identify the chronological order in which landforms were formed. Often, this non-metric or relative dating is an important step towards the understanding of a geomorphic system.

Figure 2 depicts five main relationships of interacting landforms that are characterised using the topological nine-intersection model (Egenhofer and Herring 1990) in Table 1. Here, we follow the notation of Zlatanova (2000) where ∂a is defined as the boundary of a, a^{-} as the interior of a and a° as the exterior of a. Only boundaries and the interior will be considered.

The examples described in Fig. 2 and Table 1 show that geomorphic information can be directly archived from topological analysis. However, this is not

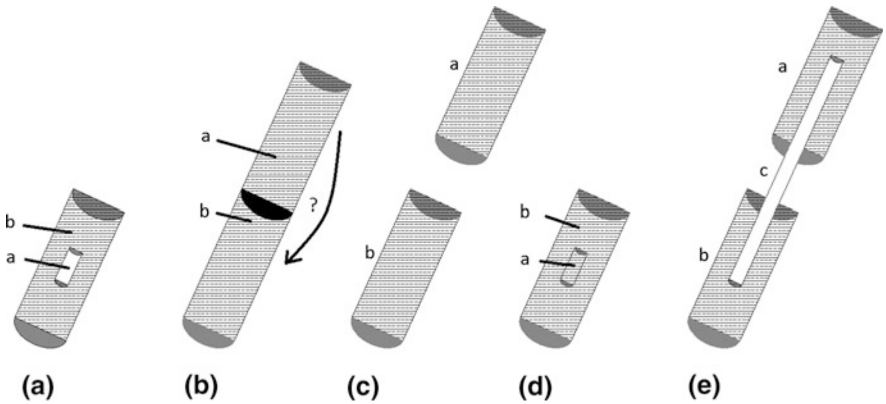


Fig. 2 Topological relationships of landforms within a geomorphic system (rf. Table 1)

Table 1 Geomorphic description of topological relationships of landforms (rf. Fig. 2)

Figure	Topological relationship	Geomorphic description
2.A	$\partial a \cap \partial b = \neg\emptyset$ $a^- \cap b^- = \neg\emptyset$	*a* lies on top of *b* and is definitely younger. *a* is formed by an erosion process on *b* followed by an accumulation. Material of *a* definitely contains material from *b*.
2.B	$\partial a \cap \partial b = \neg\emptyset$ $a^- \cap b^- = \emptyset$	*a* is adjacent to *b*. Chronological order can not be proved directly. Material exchange from the higher situated body to the lower one is most likely (needs further geometric analysis[a]).
2.C	$\partial a \cap \partial b = \emptyset$ $a^- \cap b^- = \emptyset$	*a* and *b* are disjoint. Chronological order can not be proved directly. Material exchange is still possible (needs further geometrical and topological analysis (ref. 2.E)).
2.D	$\partial a \cap \partial b = \emptyset$ $a^- \cap b^- = \neg\emptyset$	*a* lies within the interior of *b*. Genesis of *b* starts before the genesis of *a* and ended later. Implies an interruption of *b*'s building process either by temporarily high accumulation from another source or even temporarily erosion of *b*. Investigators should examine a separation of *b*.[b]
2.E	$\partial a \cap \partial b = \emptyset$ $a^- \cap b^- = \emptyset$ $\partial a \cap \partial c = \neg\emptyset$ $\Lambda\ b^- \cap c^- = \neg\emptyset$	*a* and *b* are disjoined but connected via *c*. Possibly the today filled hollow of *c* acted like a material transport path (formally an open channel?). Finding same material components of *a* in *b* or vice versa is likely (geometric inspection is needed).

[a] Since *above* or *below* are not topological terms, possible pathways have to be analysed applying geometric algorithms using f. i. a DEM
[b] This total inclusion of a smaller landform is definitely a 3D problem. 2.5D concepts are not sufficient

identified in the literature of geomorphology. That definitely shows that topology is not applied in the science of geomorphology.

3 On Problems of Semantical and Geometrical Modelling in Geomorphology

This section exposes significant difficulties in the use of application models within the science of geomorphology. These are different from the three characteristics identified by Kottman and Reed (2009), ignorance, modelling of phenomena not of mutual interest and modelling of phenomena in two different representations. One may argue that the science of geomorphology indeed is a diverse one and therefore, their researchers can be considered as individuals not belonging to the same information community. However, geomorphologists refer to almost the same paradigms and theoretical concepts (ref. Sect. 2). Thus, we argue that the main reason for reluctance to use OGC Abstract Specification based models to represent objects under investigation are firstly acceptance of technical overhead, and, secondly, problems in modelling valid 3D objects from sparse data.

3.1 A Class Model for Objects and Processes

Based on the ISO 19107, Spatial Schema (Herring 2001), Löwner (2010) proposed an application model to represent the aforementioned concepts of geomorphology. The model does not only include an object- oriented view of landforms with a true 3D geometry. It is designed to capture the internal structures and attributes of landforms as well. Both, geometry and internal states of landforms can be represented over different periods of time (ref. Fig. 3).

The abstract class `_Geoobject` represents a solid landform. As a particular spatial unit of the georelief it is a subclass of a `_GeomorphicObject`, which aggregates a `_GeomorphicSystem`. The Class `_Geoobject` has one or more associations to an abstract class `_State`. This is to represent different versions of a `_Geoobject`. Since a landform's characteristics, like geometry, may change from time to time by the impact of processes, its semantical identity remains.

A `_State` of a `_Geoobject` is characterized by its geometry and material. The latter is modelled by an `_AttributeSet`, which is not depicted here as it has no relevance in this context.

A `_Slope` as a synonym for *landform* is a specialisation of the abstract class `_Geoobject`. Referring to Dalrymple's et al. (1968) and Caine's (1974) slope model a `_Slope` may again *contain* `_Slopes`. Thus, the association *contains* represents the nested hierarchy of landforms. A `_Slope` *consists of* one or more abstract class `_Layer`. A `_Layer` may *contain* one or more subLayers. Because `_Layer` is derived from `_Geoobject`, it exhibits the association to a `_State`, too.

The proposed model seems to be a sensible approach to cover the main geomorphic concepts from a semantical viewpoint. It is able to represent the internal structure of landforms, i.e. the slope as the main landform in

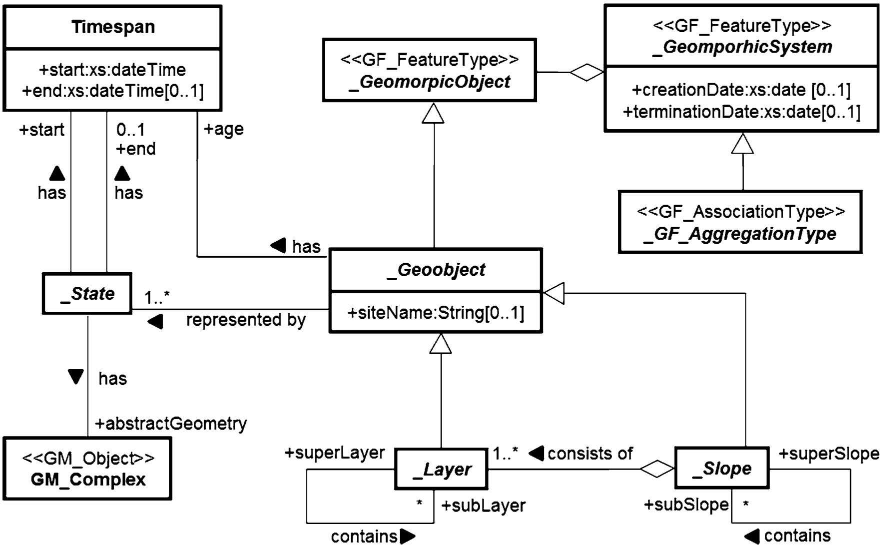


Fig. 3 Application model to represent a landform (`_Geoobject`) and its 3D geometry during different time steps

geomorphology. It consists of volumetric bodies bearing homogeneous material. These bodies themselves may be subdivided, which is an approach that makes sense, since a slope may consist of a soil layer and a regolith lying below it. Furthermore, the soil layer may be structured in different layers of homogeneous material as a result of soil-building processes over time or different sources of accumulated soil material.

In this formal representation of land surface's features the modelling of a class `_Geoprocess` serves three goals: First to store the interconnection of two or more `_Geoobjects` as a process-related accessibility; second to represent the main process that built up the landform an third to store information about the genesis of a `_Geoobject` (Fig. 4).

A `_Geoprocess` has two associations to a `_Geoobject`. It alters one or more `_Geoobjects` while a `_Geoobject` enables one or more `_Geoprocesses`. It is driven by a `_Processforce`, which might be specialised. The association of a `ComplexGeoprocess` is meant to store the genesis of a `_Geoobject`. Thus, the `_Geoobject` can be viewed as an integral of all processes over a given time span.

The formally modelled interrelationship between landform and process enables a Graph like representation of a sediment cascade (ref. Löwner and Otto 2008). The landform acting as a sediment source may then be interpreted as the "from-node" and the sink as the "to-node". Nevertheless, representation of geometry remains the greatest obstacle when applying the proposed model to geomorphology.

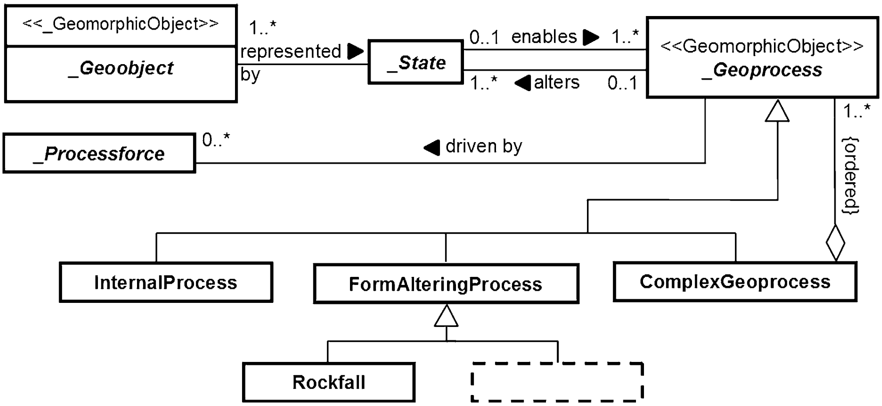


Fig. 4 Class model representing the relationship between a `_Geoobject` (landform) and a `_Geoprocess`

3.2 Acceptance of Overhead

The reviewed application models of geoobjects and geoprocesses represent geomorphology's concepts of the sediment budget and the sediment cascade. It is able to map a landform's 3D shape. Even different states of a landform and process-related accessibility can be stored. Nevertheless, geometric representation following the ISO 19107 seams to be the main problem to apply it to the science of geomorphology. Implementation int a DBMS will produce reasonable overhead and dissuades a geoscientist from leaving known but only 2.5D GIS. Realising the `_GMComplex` representing a `_State's` geometry (Fig. 3) needs to regard another 20 geometrical classes from spatial schema. Although the main literature on implementing the Spatial Schema (Lake et al. 2004) using the Geography Mark-Up Language is well known, only few geomorphologists really work with these techniques.

Describing a geomorphic system 2D or 2.5D maps are widely used (ref. Otto and Dikau 2004). Landforms are mapped using polygons. Depth information is given by semantic attributes. Actually, this is supported by the application model described above (but not depicted here). Löwner (2010) proposes an optional `FieldRepresentation`. It holds an association to a `RectifiedGridCoverage`, which is a common raster dataset. Additionally, it has a planar `LinearRing` to map the feature's 2D shape, e.g. when creating a digital geomorphological map. Unfortunately, this representation does not exploit the main advantages of real 3D modelling in terms of geometry and topology, respectively.

3.3 Data Acquisition and Modelling Problems

The science of geomorphology is working on natural 3D landforms consisting of sediment transported either by water or other driving forces. Although much is known about processes and their interaction with the land surface, no construction plans of landforms are available. In addition, subsurface boundaries of landforms are developed under different and partly unknown (i.e. regional climate) conditions. Therefore, it is not predictable that they vary in the same manner as the land surface today. On the contrary, the reconstruction of the paleo-surface representing a state of a geomorphic system at a specific time is one important research goal in geomorphology and neighbouring disciplines.

Compared to landforms, features of our manmade environment can be modelled much more easily. Take CityGML's Level of Detail 1 building model as an example (Gröger et al. 2012). Only a few points are needed to reconstruct a LOD1 building representation in terms of geometry. Usually a polygon, representing the ground surface and the height of the building is used to create a valid 3D solid representing a building's geometry. Even a LOD2 model is generated by adding a few more planar surfaces to represent the building's roof structure. Today, at least 2D digital information about infrastructure is easily available. Additional 3D datasets are available by LIDAR technologies (Zheng and Schenk 2000; Kada and McKinley 2009).

Landforms cannot be simplified this way. Extruding a planar 2D-polygon representing a landform's boundary by measured feature depth would neglect the vital role of the land surface. On the other hand, simply copying the land's surface digital elevation field to the measured depth would also be inadmissible. Since landforms are the results of partly unknown material transport processes acting over a long time on not exactly known boundary conditions, it is not possible to derive subsurface boundaries from today's land surface with levity.

Data capture may be identified to explain the significant differences between modelling approaches representing manmade structures and landforms, respectively. It is obvious that capturing a buried feature is much more difficult than measuring a construction above the surface. While the surface information on a landform is available by remote sensing, LIDAR or surveying, reconstruction of the subsurface is more difficult.

Normally, subsurface information is gathered by drillings. Boundary surfaces are identified via abrupt change in sediment properties. These are f. i. grain size or distribution, density, colour or biochemical indicators. The parameters used to determine a boundary surface depends firstly on the scientific problem, and, secondly, the theoretically background of the scientist. In most cases, changes in the environmental boundary conditions lead to changing material transport processes and therefore to different properties of the material accumulated.

In more clastic environments like alpine systems, geophysics is often applied to get subsurface information (Schrott and Hoffmann 2008; Schrott and Sass 2008). Depending on the method used, geophysical devices reveal changes in density, electronic conductivity and others. These changes are to be interpreted as boundary surfaces of the landform.

Figure 5 depicts a typically data situation on 3D landforms. In practise, a well known 2.5D surface in combination with a few points (Fig. 5a) or line information from 2D geophysical prospection method (Fig. 5b) are given to model a 3D solid. Even so-called 3D geophysical devices deliver 2D lines, albeit more than one.

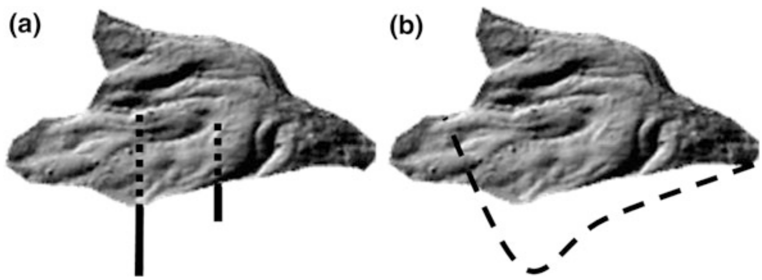


Fig. 5 Typically data situation on 3D landforms. While surface information is available, only few points (**a**) or not very reliable line information (**b**) has to be used to reconstruct a 3D solid

In geomorphology there are two ways to overcome the problems of valid geometric modelling and storing. First, this data is stored using the layer principle. 2D information is represented as a polygon in a GIS. 2.5D data is overlaid, if available. Depth information of a landform resulting from drilling data or geophysical prospection is stored as semantic information (cf. Otto and Dikau 2004; Otto et al. 2009). Second, the data is just represented in form of text, graphics and (not database) tables. As a result, research on landforms may not profit from further developments of the GI community in terms data exchange or geometrically and topologically representation and analysis.

Unfortunately, ISO 19107 Spatial Schema does not offer a valid representation of 3D geometry, neither by aggregating a surface and one or few points nor by aggregating a surface and a line. Consequently, even if the nature of a feature is proved to be three dimensional, Spatial Schema seems to be inadequate for representing under-specified 3D geometries. This directly affects the possibility to apply topological representation.

4 Linking 3D Topology to Under-Specified Geometries

We have outlined that geomorphology is a science on 3 dimensional phenomena that are changing in time (Sect. 2). Many concepts of geomorphology describe three dimensional phenomena. Therefore, a 3D application model for the representation of geometry, semantic and topology is highly desirable. Additionally, topological relationships of landforms directly reflect geomorphic principles like process-related accessibility, possible mass exchange and chronological order. However, the discussed application model in Sect. 3 seems not to be sufficient in supporting geoscientists. This was explained by data acquisition problems and complexity of the object under investigation. Since in Spatial Schema 3D topology is directly linked to a proper 3D geometric model, it may not be applicable to geoscientists.

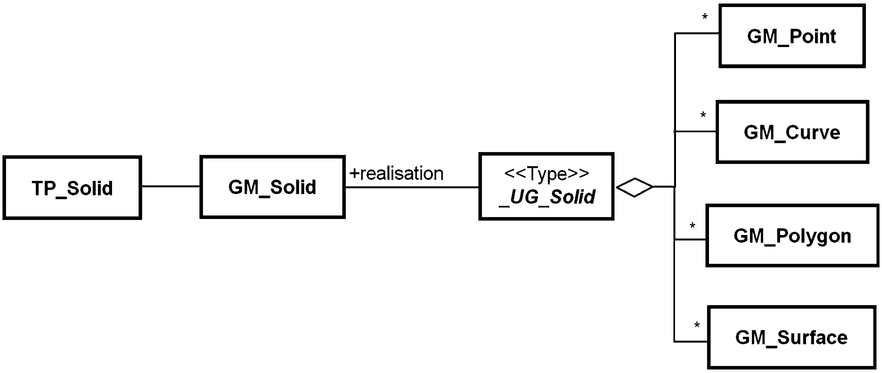


Fig. 6 Aggregation of different `GM_Primitives` to a `_UG_Solid`

Here, we present a simple approach to use the benefits of valid 3D topology even if only sparse data on geometry is available. Therefore, an abstract class `_UG_Solid` is introduced to represent an under-specified 3D geometry. Every object should be modelled as an under-specified 3D geometry that is a 3D object for knowledge reasons but not well defined for geometrical reasons. That means that no real 3D boundary representation is available, but data that enables us to reconstruct such a boundary surface. However, this boundary surface does not mean to represent the real geometry of the object. Following clearly defined conditions, an `_UG_Solid` mediates between the `GM_Primitives` `GM_Point`, `GM_Curve`, `GM_Surface`, the type `GM_Polygon` and a `GM_Solid`. Then, this `GM_Solid` is the *realisation* of `_UG_Solid` that definitely holds the 3D geometry we need to associate with the `TP_Solid` (Fig. 6).

While the realisation of a `_UG_Solid`, the `GM_Solid` class needs to be a real 3D geometry, constraints have to be defined for aggregating an _UG_Solid.

In topology the geometric characteristics are not important, except dimension. Thus, constraints on the association multiplicity only need to make sure that a real solid *could* be modelled from existing data. Of course, this solid must be closed.

Assuming a 2 or 2.5 dimensional (main) surface with an additional geometry representing the depth of a geomorphic feature this constraint can be formulated as (1):

$$(1 + \mathrm{dimMS}) * \mathrm{numMS} + (1 + \mathrm{dimDI}) * \mathrm{numDI} \geq 4$$

with : dim_{MS} = dimension of the geometry representing the main surface (e.g. 0 for a point)num_{MS} = minimum number of geometries to represent the main surface (e.g. 3 points)dim_{DI} = dimension of geometry representing the depth information (e.g. 1 for a line)num_{DI} = minimum number of geometries to represent the depth information (e.g. 1 point)

Table 2 Possible combinations of simple geometries to form an `_UG_Solid`

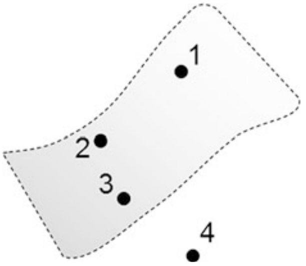
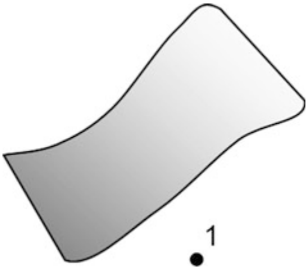
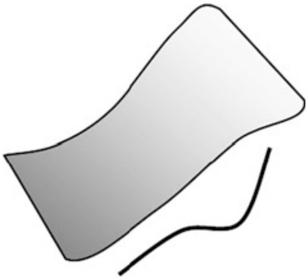
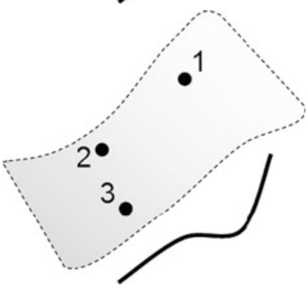
Geometries available	Comments
	The main surface (e.g. the land surface) is represented by 3 `GM_Points`. This would result in a triangle representing the surface performing a *realisation*. Depth information is just given by 1 `GM_Point` (reflecting the normal situation when a drilling is performed). Formula (1) = 4
	The main surface is represented by a `GM_Surface` (e.g. a DEM) or a `GM_Polygon`. Depth information is just given by 1 `GM_Point`. Formula (1) = 4
	The main surface is represented by a `GM_Surface` (e.g. a DEM) or a `GM_Polygon`. Depth information is given by 1 `GM_Curve` (reflecting normal situation when geophysics are performed). Formula (1) = 5
	The main surface is represented by 3 `GM_Points`. Depth information is given by 1 `GM_Curve`. Formula (1) = 5

Table 2 gives examples of typical data available in through the field work of a geomorphologist. It can be shown that the given data is sufficient to realise a 3D geometry needed to apply 3D topology.

Testing the aggregating geometries against (1) enables a valid realisation that is needed to build a `GM_Solid`. The realisation itself is a matter of implementation and needs further discussion, elsewhere.

5 Discussion

It was demonstrated that geomorphology is a science investigating natural 3D objects. These objects change their 3D shape in time due to material transporting processes. On the one hand landforms influence these processes and on the other hand they are their product. As a result, the 3D georelief aggregated by landforms is a complex system of neighbouring objects of different age and material. It is argued that OGC's spatial schema concepts are useful to represent and to analyse such geomorphic systems in principle.

Here, for the first time the explicit benefit of 3D topology for the science of geomorphology was brought out by a collection of clear examples. Analysing topological relationships of landforms directly gains our understanding in process-related accessibility of landforms and therefore material properties. Even the chronological order of landform creation can be analysed using topology. Unfortunately, 3D concepts representing geometry and thus 3D topology are not very common in the community of geoscientists.

Data acquisition and modelling problems have been identified as the main reason for the rejection of 3D spatial concepts in geomorphology. Apparently, there is no need to apply the overhead of a 3D concept, when data is sparely available. Moreover, 2D and 2.5D concepts seem to be sufficient to geomorphologist. This, as can be shown with the example of topological analysis is definitely not the case. However, overhead and a very strict formulism hinder geomorphologists to model their perception of do a real (Satzbau: of do) 3D world with 3D concepts.

Here, a simple approach is proposed to use the benefits of the abstract specification 3D topologic model, when only under-specified geometries are available. If no sufficient data is available for a clear 3D object, this approach helps to apply 3D topology on it. It was proven on examples that the formulated constraints ensure the realisation of a _UG_Solid by a GM_Solid. Nevertheless, the approach presented is incomplete. First, this must be said in terms of dimensions, since 0D–2D under-specified Geometries are not covered. Second, no relationship between the GM_Primitives has been modelled. This is surely a focus worthwhile for future research.

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