A CityGML-based Façade Information Model for Computer Aided Facility Management

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Abstract: Historically, Computer Aided Facility Management (CAFM) systems were mostly concerned with the interior of buildings. Consequently, the geospatial components of a CAFM system is mostly based on 2D CAD-based data. However, there are some applications, such as cleaning management and cost planning and controlling which require detailed geometric and semantic information on the outer shell of the building. Accurate and traceable quantitative and qualitative information for such cases are desired

In this paper, we present a harmonized data structure for geometric and semantic façade data taking into account the requirements of cleaning management. Our information model extends CityGML using the CityGML Application Domain Extension (ADE) mechanism. In order to directly store the dimensions of façade objects measured on-site or extracted from paper plans, a new parametric geometry model had to be embedded into the model in addition to the explicit boundary representation and implicit geometries defined by CityGML. Using the parametric model, façade objects can be represented by simple geometric shapes such as rectangles, triangle, etc. and by complex parametric shapes which are aggregations of arbitrary simple shapes. Moreover, defining patterns consisting of simple or complex shapes is accounted for repetitive façade structures. Our paper will describe a data structure which represents the concept "façade" which currently does not exist in CityGML and a possibility to express identical objects for both façades and buildings as well as an approach for dynamically aggregating the information on the façade and building scale.

As a proof of concept, we will also describe an implementation of the ADE based on an object-relational database management system and the development of a complex ETL-process for importing the data from various data acquisition methods into the database.

1 Introduction

The importance of facility management becomes obvious in the process of planning, design and decision making for service operations which require large investments by industrial sectors. The industrial service management is accountable for achieving productivity and in efficiently using the resources of a company assigned to producing building services. Additionally, demands of higher efficiency, transparency and flexibility on the one hand and budget shortages on the other are constant challenges for the administrators (CHAKRABARTY 2005). The huge amount of data required for long-term planning and design in the concept of FM need to be handled by a powerful management system and Computer Aided Design (CAD). The demand for accurate building information together with the high costs of running a building compels many companies to implement an efficient information management tool (BRAUN et al. 1996). The so called Computer Aided Facility Management (CAFM) attempts at automating the collection and maintenance of facility management information.

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CAFM offers the possibility to store and manage all the different categories of information needed for processing this data (SCHEIB 1998). As stated in SCHUERLE (1999) CAFM behaves as "an interface between photogrammetry, civil engineering, architecture and GIS". So the data acquisition can integrate all these methods.

Historically, CAFM systems were mostly concerned with the interior of buildings. Consequently, the geospatial components of a CAFM system for existing buildings are mostly based on 2D CAD-based data. However, there are some applications, such as cleaning management and cost planning and controlling which require detailed geometric and semantic information on the outer shell of the building. As a consequence, 3D geometric and semantic information has to be reconstructed and modified in terms of meeting the requirements of corresponding applications.

The case which is presented in this paper deals with the requirements of cleaning services for building façades in a large organization, such as an airport. In such a case the cleaning department needs accurate and traceable quantitative and qualitative information for cost estimation, preparing calls for tender and checking the quality as well as controlling the costs of the cleaning process. In this paper, we present a harmonized data structure for geometric and semantic façade data taking into account the requirements of cleaning management. The data structure is modeled as a so-called Application Domain Extension (ADE) of the international Standard CityGML (GROEGER et al. 2012). In contrast to existing CityGML ADEs, not only the semantic model of CityGML but also the geometric model had to be extended. As a proof of concept, we will describe an implementation of the ADE based on an object-relational database management system which is currently used by one of the European airports.

2 Requirements and comparison with other methods

In an analysis carried out at the cleaning department of one of the largest airports in Europe, the following requirements on façade data were identified:

- need to categorize façade elements (e.g. window, door, etc.),
- need to specify façade elements material (e.g. glass, aluminum, etc.),
- need to discriminate different height categories as they are influencing the price of cleaning services (e.g. below 4 meters, between 4 and 8 meters, etc.),
- accessibility specification (e.g. façade element only accessible from the inside of the building),
- security area specification,
- aggregation of the information on façade and building level,
- data acquisition: accounting for repetitive structures in large building complexes; support for different data acquisition methods including low-cost on-site measurements by non-specialists.

These criteria have to be applied considering the principle of traceability. Traceability is crucial when considering that the façade data is used for preparing calls for tender for cleaning services including a reliable billing with cleaning contractors. The merits of traceable data can be deeply appreciated where a huge amount of money for the corresponding services should be paid. Therefore, both the client and the provider should know the source of the costs exactly. It is important therefor, to have a link to the available CAFM system in the airport. This helps the user to trace the source of the data. Additionally a set of indicators were applied in the data model which enhance the traceability of the data in the database. For example, unique façade naming, storing a photo for each façade (where required for a specific object), storing the collecting/updating date together with the name of the collector, etc.

In this step, the first question which comes to the mind is, whether to design a new data model or to apply a pre-defined standard as the base for the existing data model. According to the above mentioned criteria and considering the complexity of the building architectures, it is more practical to use an existing data model for 3D reconstruction of building information. To include all cleaning requirements, it is also essential to choose a flexible data model which can be extend the already defined attributes and features.

With a growing interest in 3D city models various standards and data models have been designed to simulate virtual 3D buildings. Based on the studies of several models, CityGML representing a semantic model from the GIS domain and IFC, representing the BIM (Building Information Model) world are suggested as the most suitable standard and model for such a case. The reason is, both CityGML and IFC provide the 3D building models with respect to their geometrical, topological, semantic and appearance properties for the exterior and interior built environment (NAGEL et al. 2009).

IFC is a digital representation of physical and functional characteristics of a building facility. It represents all building components with respect to their geometry, topology and semantic information (NAGEL et al. 2009). IFC consists of the building components which are generally not fully observable or are even fully hidden. e. g. pipes, beams, etc. IFC comprises all information regarding the building structure and ideally, it can be chosen as a model for such an application. STEEL & DROGEMULLER (2009) propose a language for expressing transformation between BIM and bills of quantities from a building design and also the implementation of an automated quantity take-off tool. This tool brings the possibility of model modification for the end-user after which it calculates the quantitative bill based on given factors. The so called IntBM (Intelligent Building Model language) also has a facility to extend the existing model elements to include extra elements (STEEL & DROGEMULLER, 2011). The advantage here is for example an IFC *WallStandardCase* element type in a specific storey which can have values for different height categories. Ideally, this information can be extracted from existing detailed digital 3D building models and digital 2D elevations but in reality digital data for existing buildings often do not exist, are not detailed enough to provide the required information and may be structured differently for each building. It should also be considered that BIM is generally available for recently planned buildings (NAGEL et al. 2009). It needs a huge amount of time and money to obtain all already built-up sites in BIM format. A lot of effort must also be spent in dealing with the complex transformation process from existing 2D/3D data model to BIM.

Moreover, the applications such as automated quantity take-off tool also need expert users. Although, it seems to fit our case we decided not to use it because of these issues.

On the contrary, CityGML standard behaves exactly in the frame which suits the requirements of this defined by the cleaning management application with an acceptable complexity and many advantages. The capabilities of CityGML such as its semantical representation of different objects, its five levels of details, relations between objects, spatial properties, the existence of Generic city objects which enables the modelling of features not covered explicitly by CityGML, etc. (GROEGER et al. 2012) propose this standard as an ideal prototype in the context of CAFM. Through its built-in extension mechanism ADE, CityGML can be extended to meet the requirements of Computer Aided Facility management (BLEIFUSS et al. 2008). Another advantage of this standard is related to the fact that CityGML is representing only visible objects. So it is more close to the approaches of data collection such as on-site measurements, photogrammetric registration or surveying techniques.

As a conclusion of the examination of different methods and models, our information model extends CityGML using the CityGML ADE mechanism.

3 Data Model Design

In contrast to existing ADEs (e.g. Noise ADE; INSPIRE ADE), both the semantic and the geometric model of CityGML had to be extended. The UML class diagram which is shown in figure 1 represents the data model subdivided into classes originating from the CityGML schema (blue-colored), classes from the spatial schema defined by ISO 19107 (ISO, 2003) (green), classes extending the semantic model of CityGML (beige) and classes defining the new parametric geometry model (yellow). In the following sections, the extensions of the semantic and the geometric model of CityGML are discussed in detail.

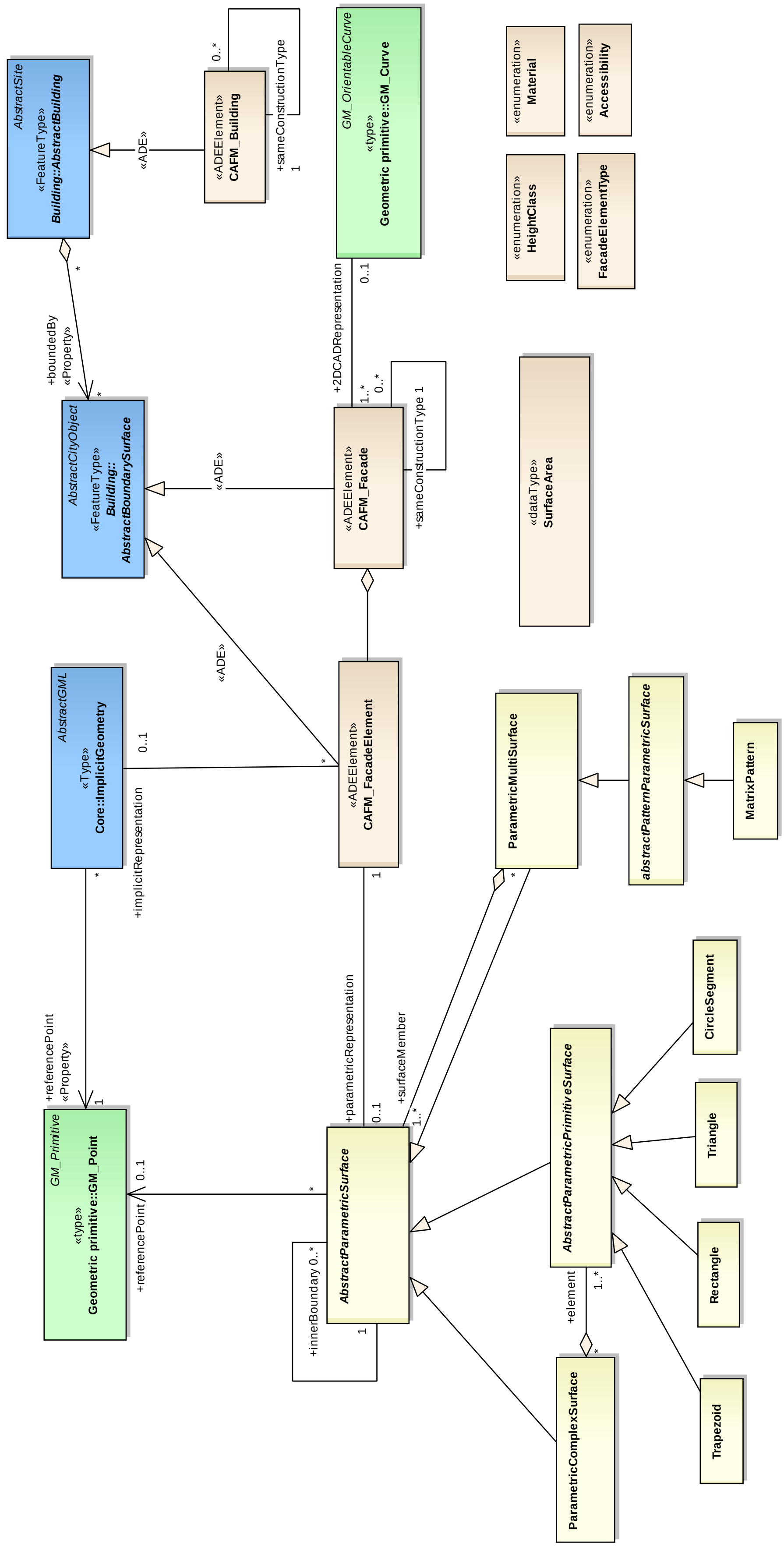

Fig. 1: Overview of the semantic model

3.1 Extension of the Semantic Model of CityGML

CityGML defines semantic classes for representing the outer shell of a building (WallSurface, RoofSurface etc.) but does not explicitly model the concept “façade”, which is of major importance to the application described in this paper. Therefore, the CityGML schema has to be extended using the ADE mechanism. We represent the concept “façade” as an aggregation of façade element objects.

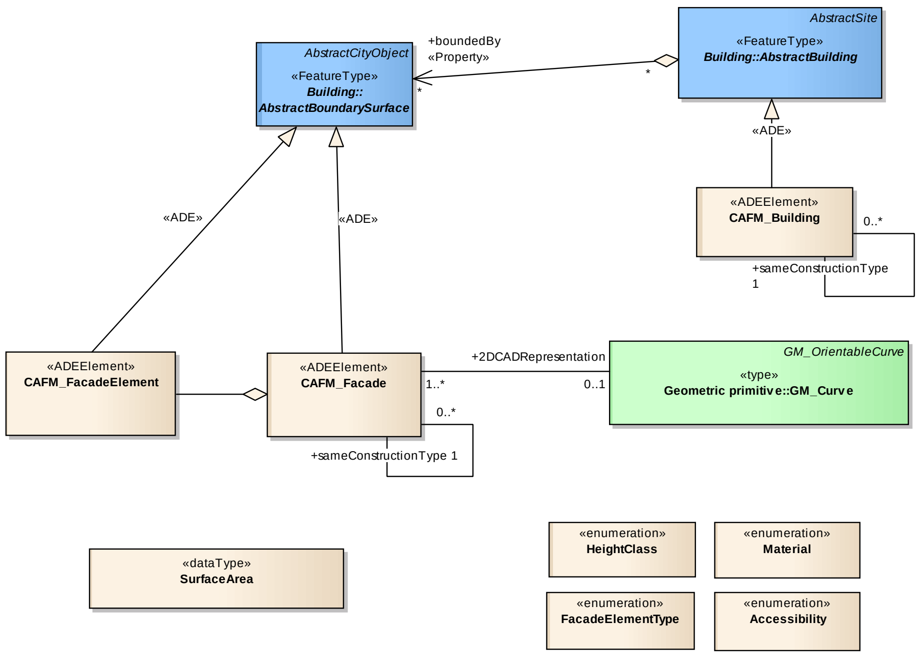

Fig. 2: Extensions to the semantic model of CityGML

Figure 2 shows the relevant part of the UML class diagram. By deriving the classes *CAFM_FacadeElement* and *CAFM_Facade* from the CityGML class *AbstractBoundarySurface*, both classes inherit a range of useful properties which support the traceability of the data, such as *gml:description*, *creationDate*, the aggregation relation between a building and its façades and façade elements and the ability to store external references with façades and façade elements. External references can be used e.g. for scanned paper plans or photos stored in a document management system. Façade elements can be further distinguished by means of their attribute *type*. The values of this attribute, e.g. “outer skin” or “sunshed”, are specified by the enumeration *FacadeElementType*. The attribute *areaToBeCleanedOutside* specifies the surface area of the façade element to be cleaned. As some façade elements (e.g. windows) have to be cleaned from the inside as well, there is an optional attribute *areaToBeCleanedInside*. Both attributes have a complex data type named *SurfaceArea* which describes the surface area along with information on the height category, the material and on the accuracy of the surface area. The complex data type *SurfaceArea* is reused in the classes *CAFM_Facade* and *CAFM_Building* in order to store aggregated information on the surface area to be cleaned at façade and at building level. At the façade element level, the surface area has to be stored explicitly for each façade element. At the façade and the building level, the value of the surface area attribute is dynamically calculated at runtime by aggregating the information from the façade elements related to a specific building or façade. The association between a façade object and a GM_Curve object from ISO 19107 allows for relating a CAFM_Facade object to a 2D representation of the façade in a 2D CAD plan, e.g. line in a floorplan of a building.

In large industrial and office facilities entire façades and entire buildings are often repeated in building complexes. This fact is accounted for by defining reflexive associations for the classes *CAFM_Facade* and *CAFM_Building*. This makes it possible to express that there are identical objects for both façades and buildings. By a constraint, only the object at the association end named "*sameConstructionType*" of these associations are aggregations of CAFM_Facade or CAFM_FacadeElement objects respectively.

Figure 3 shows a possible combination of values from the enumerations *FacadeElementType, HeightClass, Material* and *Accessibility.*

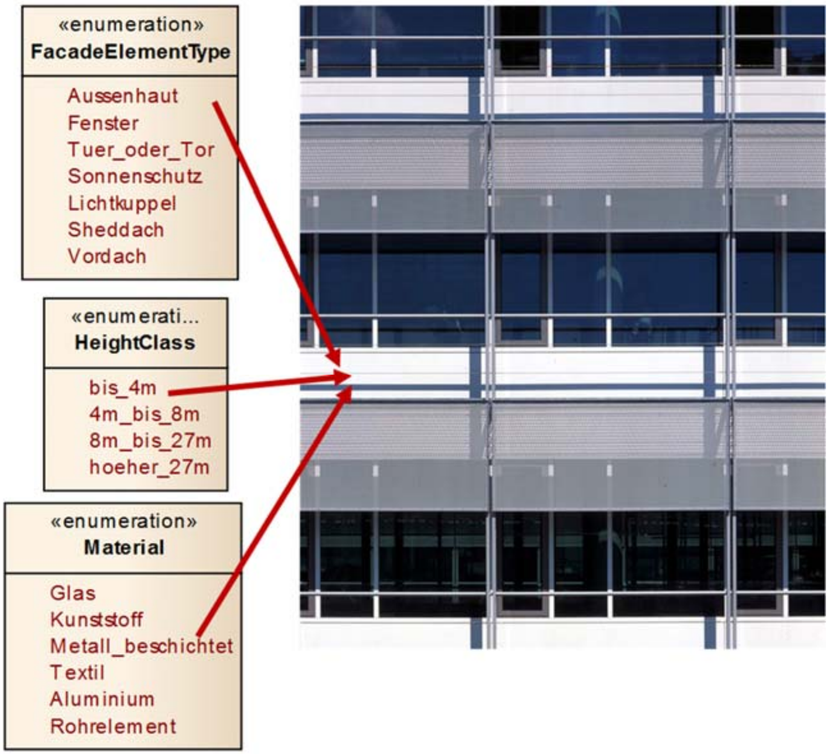

Fig. 3 Possible values of the enumerations FacadeElementType, HeightClass, Material and Accessibility

3.2 A Model for representing Parametric Geometry

The geometry of façade element objects can be described using either explicit boundary representation geometries using the association between a boundary surface and its geometry inherited from the CityGML class *AbstractBoundarySurface* or by using the implicit geometry concept of CityGML, which is in our case used to relate a façade object with an object in a CAD drawing. In order to directly store the dimensions of façade objects measured on-site or extracted from paper plans, a new parametric geometry model had to be embedded into the model as a third option to store geometry. This was necessary in order to fulfill the requirements regarding the traceability of the information and to allow for applying low-cost data acquisition techniques such as readings from paper plans or on-site measurements with laser distance meter or measuring tapes.

Using the parametric model, façade objects can be represented by simple geometric shapes such as rectangles, triangles, etc. and by complex parametric shapes which are aggregations of simple shapes. In addition, the parametric model allows for defining patterns consisting of simple or complex shapes in order to account for repetitive façade structures.

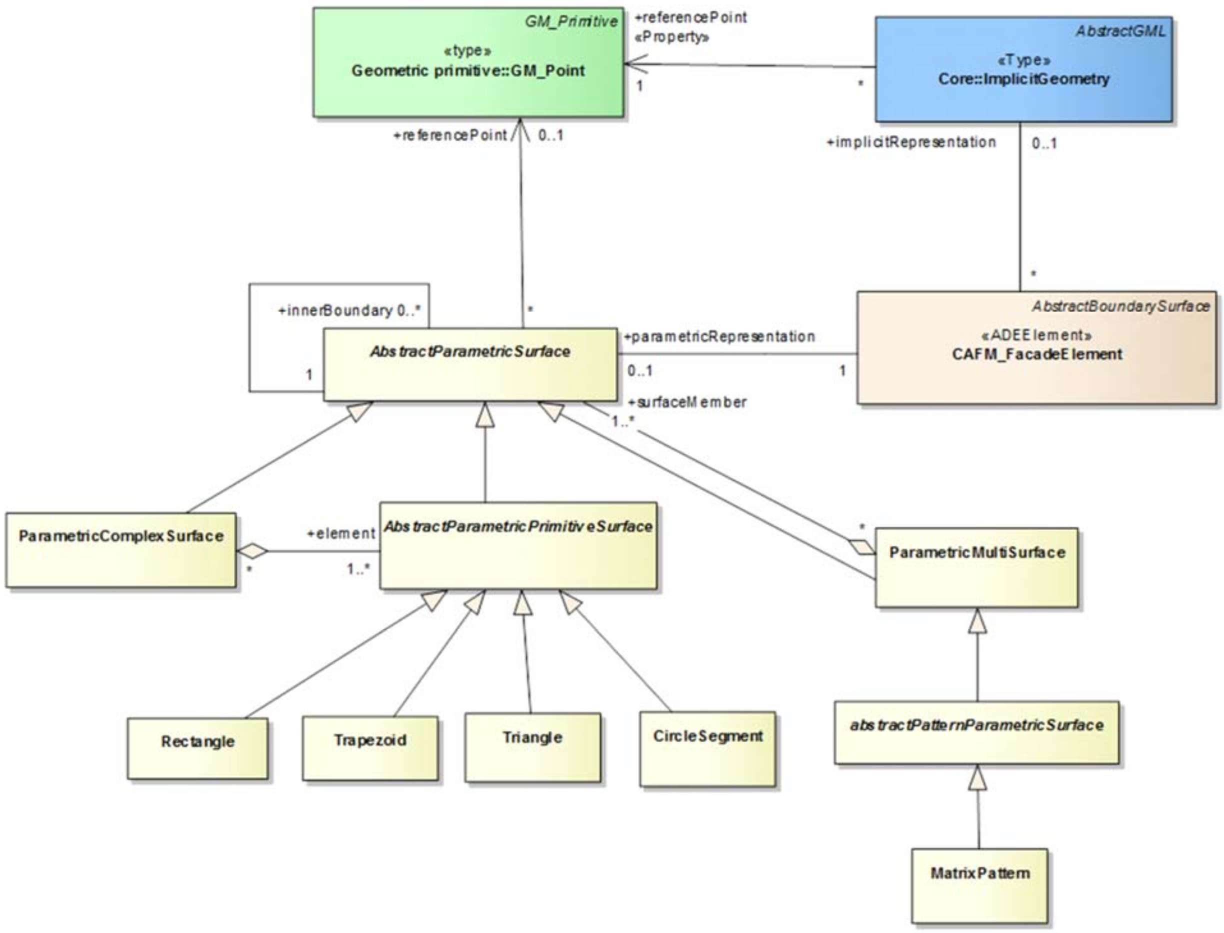

Fig. 4: Overview of the parametric geometry model

Figure 4 shows a class diagram of the new parametric geometry model. The class *AbstractParametricSurface* defines the optional attributes *azimuthAngle*, *rollAngle* and *tiltAngle* as well as an association with a *GM_Point* object from ISO 19107 (ISO, 2003) which may optionally be used for geo-referencing the parametric shape. A void area in a specific parametric shape can be defined by means of an association between the parametric shape representing the outer boundary of an object and one or more parametric shapes representing the void area. Additionally, an operation is defined for calculating the surface area of the parametric shape object. We defined the classes *Trapezoid*, *Rectangle*, *Triangle* and *CircleSegment* representing parametric primitives which are quite common for representing elements of façades of contemporary office-type and industrial buildings. More complex shapes can either be represented by *ParametricComplexSurfaces* which aggregate topologically connected parametric primitives of any type or by *ParametricMultisurfaces* which aggregate arbitrary types of *AbstractParametricSurfaces*. An example of a ParametricComplexSurface is shown in figure 5.

Fig. 5: A complex parametric shape object aggregating a trapezoid and a triangle primitive

Repetitive patterns, as shown on Figure 6 can be represented by objects of the class *MatrixPattern* which is a specialization of *ParametricMultiSurface*. Members of a *MatrixPattern* may therefore either be parametric primitives or parametric complexes.

4 Proof of Concept

To prove the concept of the data model, it was implemented in an ORACLE database as an extension of the 3DCityDB database schema (http://www.3dcitydb.org), an open source database schema for storing CityGML data. First, a set of mapping rules were defined in order to derive the relational schema from the object-oriented semantic model. This also includes adding triggers, functions and procedures into the database, e.g. for implementing the *getSurfaceArea* method of the class *AbstractParametricSurface*. In a second step, a tool for importing data had to

be developed. The transformation of the raw data provided in spreadsheet and CAD format was implemented via the software FME.
The architecture of the tool is based on thirteen basic so called FME workspaces, each responsible for populating a part of the tables. More than forty error handlers check the validity and availability of the input data based on a set of rules defined from the requirements. They raise the error/s and terminate the process when the input data do not obey the rules. In such a case, the user needs to resolve the problem and re-run the procedure. This function guarantees the quality and exactness of the output results.

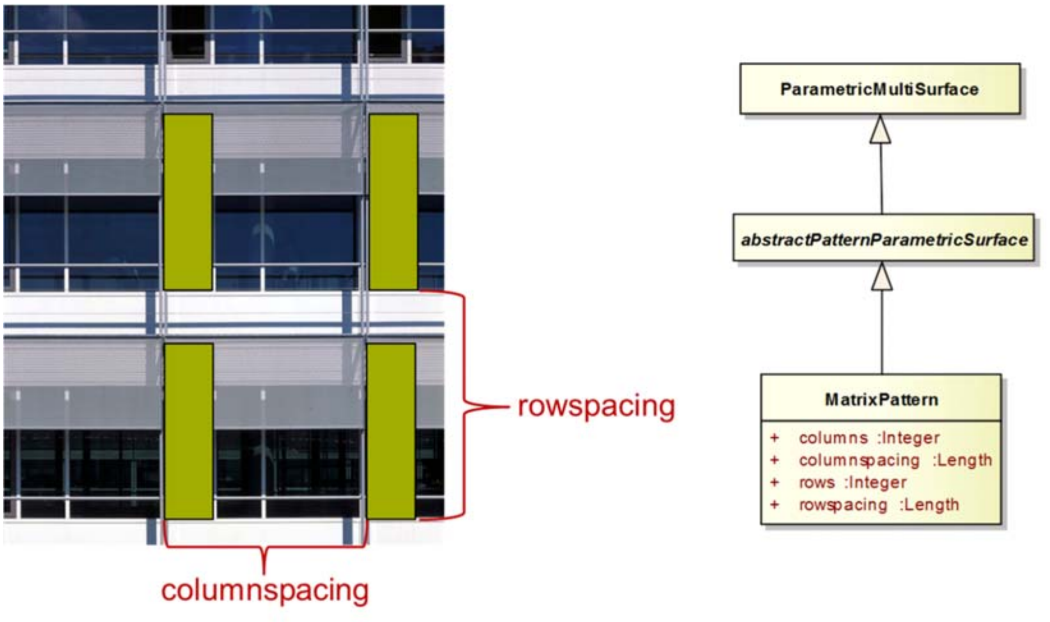

Fig. 6: Example of a matrix pattern consisting of primitive shapes, in two rows and two columns

5 Conclusion

As an OGC standard and an exchange format for 3D city models, CityGML offers the opportunity to expand its model through an ADE. In this work, this capability was used to integrate the requirements of façade cleaning services in the context of Computer Aided Facility Management (CAFM) into CityGML.
Besides extending the semantic model of CityGML based on the requirements of CAFM using the CityGML ADE mechanism, a new approach to storing geometry which best fits low-cost on-site measurements and readings from existing paper plans was established. In this approach, an object-oriented data structure for representing parametric geometry was defined. Apart from its alignment with simple, low-cost data acquisition techniques, the parametric geometry model allows to trace the calculated surface areas back to the original measurements and therefore greatly helps to ensure data quality as required by the cleaning management use case
The semantic extensions of the CityGML schema can be handled by any software supporting the ADE mechanism (e.g. FME). At the moment, this is not true for the parametric geometry model

because CityGML supports only boundary representation and implicit geometry. In an implementation of the parametric model, of course a function for converting the parametric geometries to boundary representation could be integrated. This would require that the data contains the information defined by the optional geo-referencing mechanism of the parametric model. In case the geo-referencing information exists, the parametric geometry could even be used to generate 3D model of the building at relatively low cost.

6 References

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