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Modeling of Urban Planning Actions by Complex Transactions on Semantic 3D City Models

Maximilian Sindram and **Thomas. H. Kolbe** [a]

[a] *Technische Universität München, Arcisstr. 21,80333 Munich, Germany*
(maximilian.sindram@tum.de, thomas.kolbe@tum.de)

Abstract: Decision support for environmental planning requires the impact analysis of envisaged actions. These actions often are adapted from measures specified in regulations or other legal documents given in natural language. Their realization involves (possibly complex) changes to specific parts of the environment. For example, the energetic retrofitting of a building typically comprises the insulation of the façade and replacement of the windows. In general, different actions or combinations of actions can be chosen for the optimization of certain key performance indicators (KPI) like the overall energy demand or CO_2 emission of a city district. This requires the assessment of the applicability of the possible actions to the individual elements of the environment, their potential interferences, and their effects on the KPIs of interest. The paper presents an ontology for the formal modeling of planning actions as complex transactions on the entities of virtual 3D city models using UML. This comprises the representation of the required transactions on the underlying objects of the city model, the preconditions for the applicability of the action, the required actual resources like duration and costs if the actions would be performed in the real world. Also the affected KPIs like 'CO_2 emission' or 'energy demand' are enumerated together with qualitative indicators stating whether the action will have a positive, a negative, or no effect on them. The model builds upon the international standard CityGML of the Open Geospatial Consortium for the representation of semantic 3D city models which is used worldwide by an increasing number of cities, regions, and even entire countries. The proposed model allows to map the measures and actions described in legal documents and regulations (e.g. energy savings regulations) onto complex transactions on objects from virtual reality. This enables planners to work with high level transactions directly corresponding to measures and actions as described by legal frameworks instead of individually manipulating the many objects, attributes, and relationships within a geoinformation system required to simulate the outcome of a complex real world action. We illustrate the concept for the use case of strategic energy planning in an urban quarter in London where decisions on the sensible degree of retrofitting of individual buildings in an socially disadvantaged district have to be made.

Keywords: Semantic 3D City Models, Decision Support, Modeling Planing Actions, CityGML, GIS

1 INTRODUCTION

The concept of urbanization comprises the challenges cities need to cope with in the future. They are characterized by an ever-increasing population density due to the ongoing rural depopulation in conjunction with an expansion of the original urban area. Thus, the complex system of the city needs to be adapted to the new circumstances and changed structures. In addition, global and regional interests such as the reduction of CO_2 emissions or the improvement of socially disadvantaged housing estates must be planned and implemented in a sustainable manner. To this end, laws and regulations are phrased that define the urban planning actions or measures. These texts can be very well understood by humans, but computer systems require a strict formal representation of these requirements in order to calculate complex scenarios in simulation runs. The degree of formalisation increases from informal political texts over ordinances up to a formal ontology for urban planning actions. In the planning process reliable support systems are crucial for answering open questions in urban context and for the evaluation of planned scenarios.

Urban planners and decision-makers increasingly make use of semantic 3D city models as an information hub and basis for different simulation models (see Kaden and Kolbe [2013]; Kaden et al. [2013]). The advantage over conventional approaches that classify, for example, the simulation domain according to a symmetrical grid with an edge length of 1km and use this as the smallest unit of reference or use diffuse reference areas as statistical boundaries (see Koppelaar et al. [2013]; Keirstead and Sivakumar [2012]; Jessberger et al. [2011]; Hofman et al. [2011]) is that the entities of virtual 3D city models are discrete, virtual representatives of the real world objects in the city. Approaches from computer science in civil engineering (see Bazjanac et al. [2011]; Erhorn-Kluttig et al. [2013]; Ng and Ai [2013]) have a very high level of detail which refers both to the modeling depth of the building as well as to the possible actions. However, the tools do not allow for a strict formal representation of these actions as transactions on the entities of the virtual city/building models. Thus, it is not possible to model urban planning actions that are applicable to different areas.

For computer-based simulations spatially and thematically differentiable objects are required. However, the geometry of the city objects and their appearance says nothing about their semantics. Therefore, 3D computer graphic models are not sufficient. The thematic decomposition of the city and the attributive augmentation of theses objects are closing this gap. Thus, all simulation models from different domains relate to a consistent data base with an common understanding of the separation of the city into its components. Semantic 3D city models are increasingly being created and maintained by the municipalities and regional authorities and thus form a reliable and sustainable source of high-quality data for integrated city system modeling. The currently established ontologies (CityGML, IFC) for the description of semantic 3D city and building models allow for the representation of static city states at fixed times.

Planners make their decisions based on Key Performance Indicators (KPIs). These KPIs can be calculated on the basis of semantic 3D city models. In Kaden and Kolbe [2013] the heat energy demand of buildings is estimated based on the topological and geometric input values of the buildings. Figure 1 illustrates the problem that it is not possible to determine the state of a city at future time points. In order to allow for the calculation of the effects on KPIs based on city models a formal data model is needed to model planed actions as transactions on current virtual city models. Thus, city models for future time points are not generated based on collected data but derived from current city models by applying the modeled urban planning actions. There is no concept known that allows to map urban transformation processes to complex transactions on the entities in 3D spatial databases or geographic information systems and to model them formally. The approach that is described in this paper uses the fact that objects in virtual 3D city models represent the real objects and their properties. There is a need for a formal model which allows for the execution of planned actions at the level of virtual 3D city models and simulate the effects in the future. With the help of these simulated future versions of virtual city models which can be generated from different scenario calculations the expected impact of planned actions on the KPIs can be calculated. In this paper, the concept of semantic modeling of actions will be discussed on the basis of the application schema CityGML (Kolbe [2009]).

2 PROPERTIES OF URBAN PLANNING ACTIONS

Planning actions in the urban context are defined as the sum of all anthropogenic and intended processes causing a geometric or attributive change of the state of the city or their components. Two states of actions can be distinguished: (i) Prototypical actions are partly instantiated objects that represent a general framework of an action which still has no direct connection with specific objects in the city. These actions formally comprise generally defined transformation rules respectively operations. In addition, conditions are formulated which must be fulfilled for a successful execution of the action.

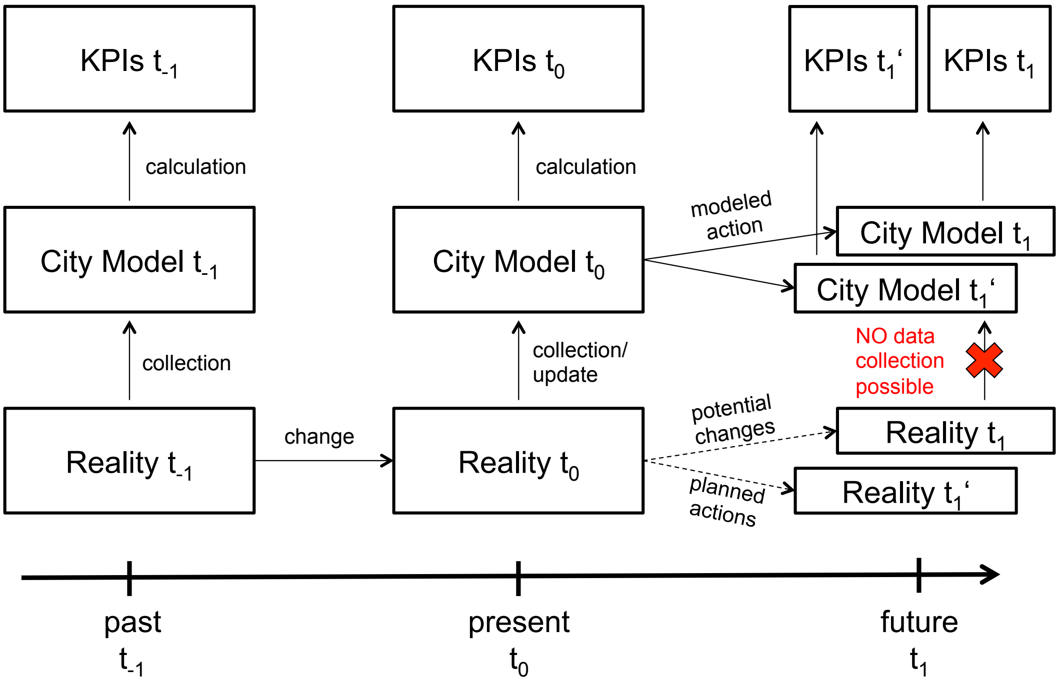


Figure 1. Current use of 3D City Models in planning processes.

These conditions apply to both properties that must be given by the input data as well as the desired effects that are to be achieved with the implementation of the action. By instantiating these prototypical actions with specific parameters from the entities of the virtual city model they change to (ii) specific actions.

’Specific actions’ are also potential actions. They are offered to the decision-makers as a preselected set of potentially executable actions. The actions are performed as transactions on the city model only when a decision has been made. Thus, for example, further/new simulations can be executed on the city model to analyze the effects and to quantitatively determine the changes in KPIs. Figure 2 shows that the structure of the action is maintained in the two states. By instantiating the prototypical action they are applied to the concrete city object. Figure 2 illustrates that actions (A) may exist of sub actions (SA). One action could be a political instrument which funds energetic refurbishment of buildings with a total amount of 1 billion Euros. This still very generally worded action consists of e.g. a sub action that aims at the refurbishment of the structure of a building. This sub action in turn consists of two further single actions. One of these actions could be a façade insulation (S_1). Insulation material will be applied to the wall surface of a building and thus the coefficient of heat transmission (U-value) is improved. The second single action could be a window renovation (S_2) replacing the windows in the case of built-in double glazed windows by triple glazed windows. Since these actions are not bound to specific buildings on a street but could be applied to all suitable buildings their status is ’prototypical’. Through the instantiation with quantities taken from the respective buildings of the 3D city model they become ’specific actions’. In the example illustrated in Figure 2 the actions for façade insulation and window renovation were applied on the building 11 and 13. The building number 12, however, was omitted due to preservation orders.

3 DATA MODEL FOR SEMANTIC TRANSACTIONS

The properties of actions and the concepts discussed in Chapter 2 are implemented as a UML class diagram. The central class of the data model is the abstract class *_AbstractAction*. The composite design pattern shown in the UML class diagram (see Figure 3) allows for the modeling of arbitrarily

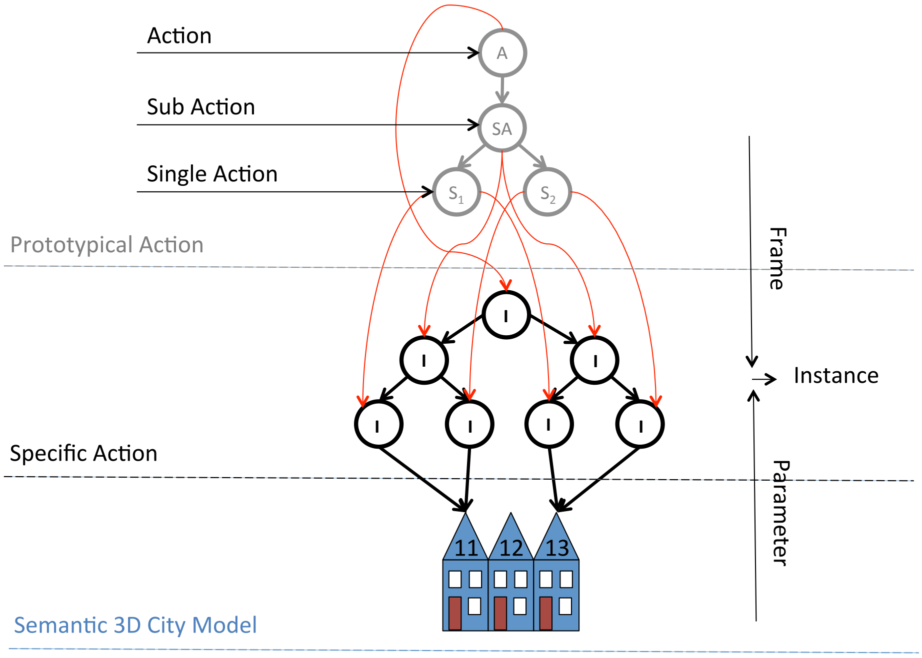


Figure 2. Difference between prototypical action and specific action. (A = Action, SA = Sub Action, S_1 and S_2 = Single Actions with no further breakdown, I = Specific Action respectively full instance of action)

deep aggregation hierarchies of actions. The following list describes the essential elements of actions and their implementation in the UML class diagram:

KPIs

Actions always pursue a specific goal that has an impact on some key performance indicators (KPIs). These objectives can be of different nature (ecological, energetic, monetary, cultural) and be either politically, economically, or personally motivated. Especially for energy simulations these key indicators are of importance (see Krüger and Kolbe [2012]). In the data model the class *KeyPerformanceIndicator* represents this concept. The attributes *targetValue* and *unit* are storing the desired value of the KPI and its unit. The attribute *description* allows for a short explanation of the action. The direction of the impact of the action can be defined in the attribute *impact*. The attribute can have a value of enumeration data type *ImpactType*. The '$>$' character stands for a positive change of the KPI, the '$<$' character stands for a negative change. If the action has no effect on the KPI the attribute takes the equal sign as the value. An unknown or uncertain effect on the KPI is expressed by the value *unknown*.

Categories

Actions can be classified in terms of their mode of operation into three different categories. Actions can extend the existing city system or their parts by new objects (e.g. planning and construction of a new heating plant). Furthermore, actions can change existing objects (e.g. façade renovation of all buildings in a street). The removal of an old district heating line represents the third category of actions; objects are completely removed from the city model.

Relations

Actions can be composed of other actions which follow up a common goal, but can refer to different city objects or components. An action that provides an energy-efficient renovation of a building stock consists, for example, of an action for façade refurbishment, another action for the modernization of the heating system and an action of installing a photovoltaic system on the roof. All individual actions together are combined to one single action with the same goal. Measures may also pursue conflicting

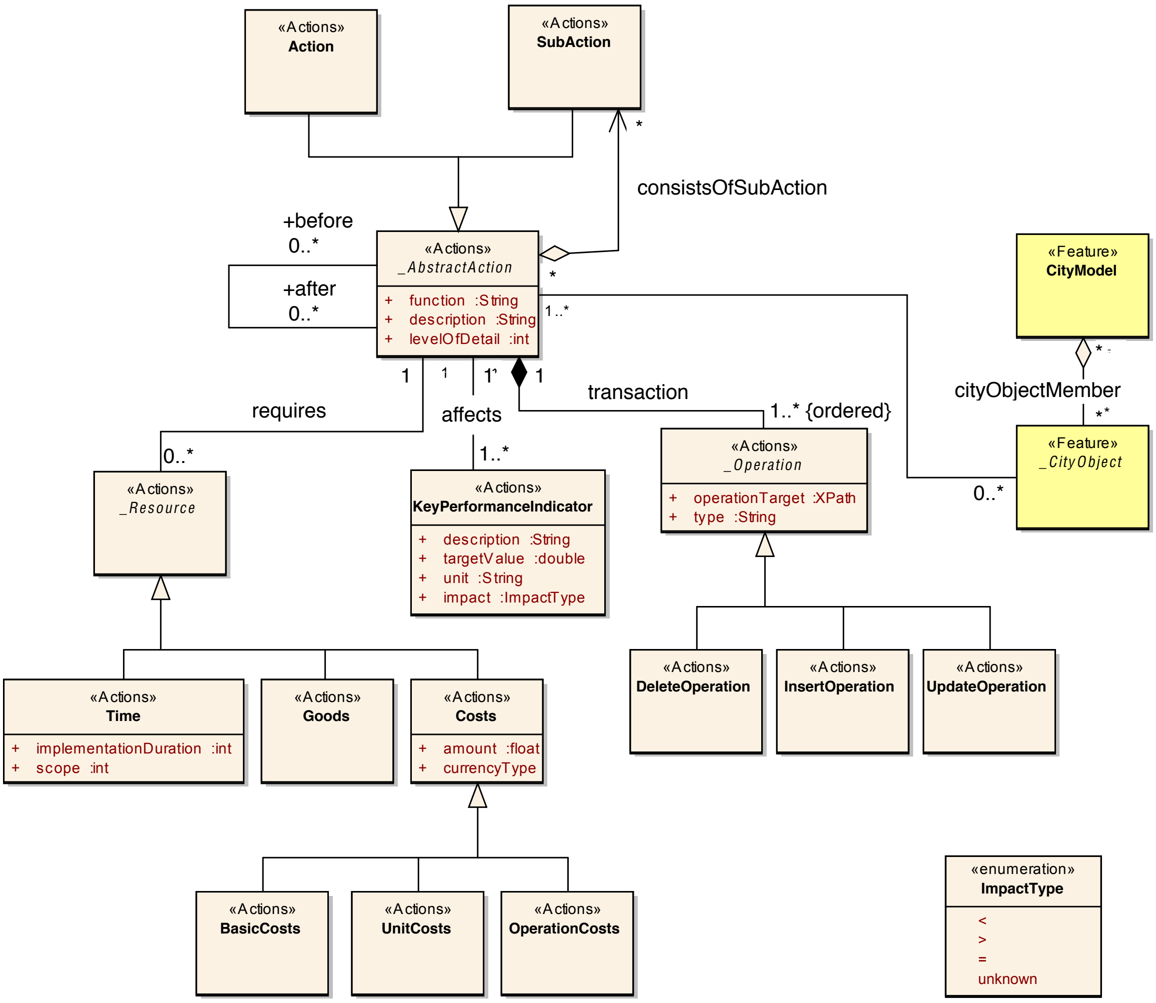


Figure 3. UML class diagram of the data model for semantic planning actions.

goals. This means that one or more KPI change in different directions. Thus, a façade renovation is in conflict with a conservation action that will preserve the original view of a façade. Actions that are using the same resources compete with each other. A roof provides limited space to install a solar thermal panel and a photovoltaic panel. However, in order to achieve an optimal energy yield the results of the two actions should be compared to each other. Actions can be complementary. The expansion of bike paths and the introduction of car-free zones both lead to reduced CO_2 emissions in the affected region. Actions that refer to the same KIPs and change them qualitatively to the same direction are complementary.

Reference units

Actions can be applied to different reference units from the city model. These reference units are ranging from administrative or statistical boundaries at different scales to specific objects such as buildings or other parts of 3D city models. These boundaries are determined both by the availability of input data and on the other side by the level of detail of the specification of the actions. A major advantage of using a combination of the sharp object entities in the city such as buildings or roads together with administrative boundaries is that these levels are consistent and persistent. They also correspond to the specific decision levels for which there are clear responsibilities and jurisdictions. For example, the costs of a renovation of a building can be directly related to the building owner.

Operation

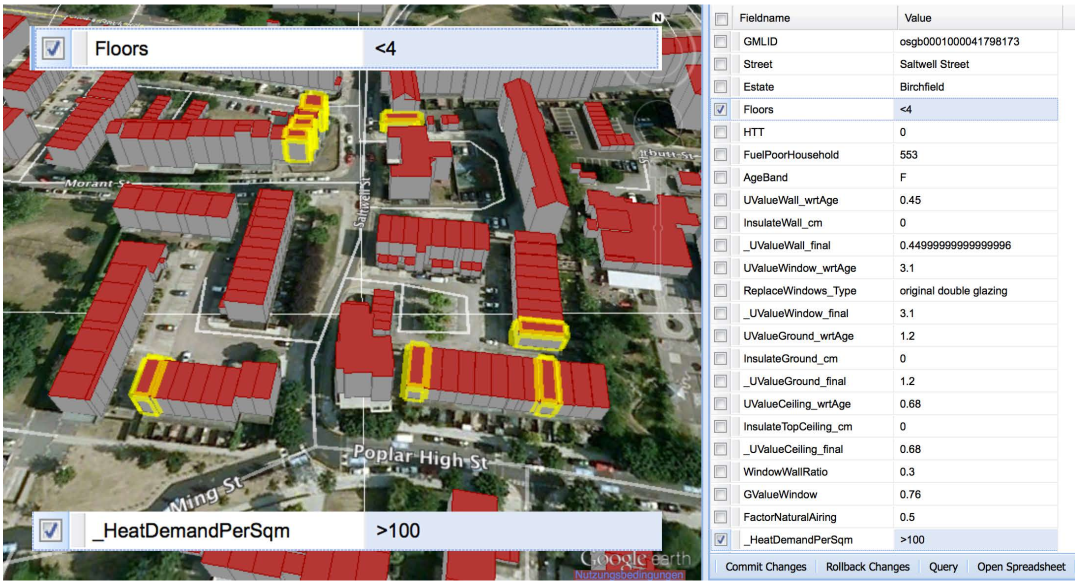
As actions always cause changes of the city model, they consist of a set of operations on the city model objects. Analogous to the classification of the actions into categories, operations can also be divided into three types which are related to the geometry or the attributes of the objects. The delete operation removes values from attributes or even entire urban objects. New attribute values or objects are inserted into the existing 3D city model by an insert operation. Changes to existing entities are defined by an update operation. Transactions to the reference objects are realized in the UML class diagram by the abstract class *_Operation*. This class has an attribute that stores a pointer to a specific element of the associated 3D city model. This element can be an object or an attribute of an object. An action consists of at least one or more operations that are performed in an ordered sequence. The abstract class *_Operation* generalizes the classes *DeleteOperation, InsertOperation* and *UpdateOperation*.

Resource

An essential advantage of a formalism for the semantic representation of actions is the possibility to estimate the effects of planned actions in reality by performing them on the virtual 3D city model before their actual implementation. Thus, the required resources are estimated at the city model and consumed virtually. These resources may be required times for the implementation in reality. In addition, resources can be of material nature e.g. insulation materials for roof insulation. To assess the cost-effectiveness of an action resources can represent costs that consist of basic costs, unit costs, and operating costs. Thus, the financial impact of an planned action can be estimated for different scenarios. In the data model resources are represented by the abstract class *_Resource*.

4 USE CASE: PLANNING OF ENERGETIC RETROFITTING IN LONDON

Figure 4 shows a part of the city model of London. This model follows the international standard CityGML and is available in level of detail 2 (LoD2). The city of London is facing the challenge to fight the so-called 'fuel poverty', i.e., the available household income is inadequate for an adequate heat supply. To address this problem the Energy Companies Obligation (ECO) funding program was initiated in the United Kingdom. The program defines buildings with more than 4 storeys as difficult to rehabilitate.



☑ Floors <4

☑ _HeatDemandPerSqm >100

☐	Fieldname	Value
☐	GMLID	osgb0001000041798173
☐	Street	Saltwell Street
☐	Estate	Birchfield
☑	Floors	<4
☐	HTT	0
☐	FuelPoorHousehold	553
☐	AgeBand	F
☐	UValueWall_wrtAge	0.45
☐	InsulateWall_cm	0
☐	_UValueWall_final	0.44999999999999996
☐	UValueWindow_wrtAge	3.1
☐	ReplaceWindows_Type	original double glazing
☐	_UValueWindow_final	3.1
☐	UValueGround_wrtAge	1.2
☐	InsulateGround_cm	0
☐	_UValueGround_final	1.2
☐	UValueCeiling_wrtAge	0.68
☐	InsulateTopCeiling_cm	0
☐	_UValueCeiling_final	0.68
☐	WindowWallRatio	0.3
☐	GValueWindow	0.76
☐	FactorNaturalAiring	0.5
☑	_HeatDemandPerSqm	>100

Figure 4. Selected buildings with an annual heat energy demand per square meter greater than 100 kWh/m^{2}a and less than 4 storeys. Scene from a CityGML model of London.

The selected buildings from Figure 4 meet the criteria for funding. By the KPIs floor number and annual heating energy consumption per m2 the potential building stock was selected. The energy calculation methods based on the CityGML building model are described in detail in Kaden and Kolbe [2013]. The selection of potential building is done automatically based on the conditions for the KPIs that were defined in the data model. In the implementation of this use case within the current decision support framework there are still many modifications on the attributes and objects of the building model necessary. Only through the implementation of the proposed data model for planning actions the planners are able to perform further actions e.g. energetic refurbishment actions on the virtual entities and do not have to care about the complex transactions on the virtual city model. Their focus lies on the changing effects on the KPIs.

5 CONCLUSIONS AND OUTLOOK

For the collaborative planning of urban systems a common understanding about the decomposition of the city into its constituent parts is necessary. This common base is given by semantic 3D city models following the international standard CityGML. City models that are represented according to this ontology, however, only represent a static view of the city objects at fixed times. In this paper a first concept was presented which allows to model planning actions as semantic transactions on the entities of such semantic 3D city models. By the means of this concept, it is now possible that planners can perform high-level urban planning actions, intended in reality, on the virtual city model and estimate the real impact. Actions are first modeled as prototypes by specialists. These actions are available to the planner in a pool of potential measures. By the application of an action to a specific object the prototypical action changes to a specific action. A major advantage of actions modeled as objects and referring to the entities in CityGML is the transferability of prototypically formulated actions to city models of different cities.

The data model presented in this paper is a first proposal for the modeling of actions. In the future, a more sophisticated consideration of preconditions of actions is required. In order to connect e.g. a building to a district heating system a connection must be ensured to the system by a utility company in advance. Both the connection of the building to the utility network and the installation of a new heating system in the building are individual actions. The successful connection to the utility network is mandatory for the successful implementation of the installation action. The ability to model these conditions is not yet represented in the data model. Furthermore, the proposed data model needs to be prototypically implemented as a tool.

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