4.3 The BCH-ontology

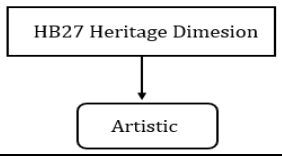
In this section the final ontology is presented, organized according to the cycles of preventive conservation.

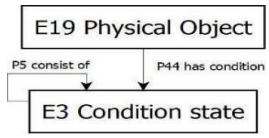
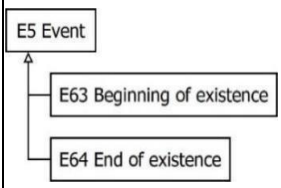
The final model consists of an ontology with 180 classes, out of which 28 are from MONDIS ontology, 34 from Geneva-CityGML, 53 from CIDOC-CRM, and 65 new classes have been added. The ontology also includes 129 properties (57 inverse) (Annex III).

4.3.1 CH-ontology key concepts.

In a later section, the main classes and properties of the BCH-ontology are explained. Key concepts used in diagrams are presented in Table 4.13. Some name classes used in previous sections are changed to synonyms in order to reuse the classes from the selected ontologies.

Table 4.13 Diagrams key concepts used for the construction of the BCH-ontology.

Term	**Description**
Class 	A class represents a category of items that share a number of common features. It is represented by a rectangle.
Package 	A package represents a group of classes that share some common characteristics.
Instance 	A class or a property is instantiated when a real world value is assigned to it. For example 'Artistic' is an instance of the Heritage Dimension class. The value instantiated is represented by an ellipse. A single arrow points to the instantiated value.

Property  	Properties define relationships between two classes. They are formally defined by the specification of a domain class and a range class. Properties are represented by a black arrow starting at the domain and pointing to the range.
Inheritance  	Ontologies are based on taxonomical representations which show the hierarchical relationship among the ontology terms. This hierarchical representation is also known as inheritance and leads to classes acquiring a role of subclass or superclass. All instances of the subclass are also instances of its superclass, and the properties of the superclass are also applicable to the subclass. Inheritance is represented by a white arrowhead where the subclass is pointing to the superclass.

4.3.2 CH-ontology packages

BCH-ontology Classes Packages have been used in Fig.4.12 for readability reasons. Fig.4.13 through Fig.4.15 show the classes included in each package.

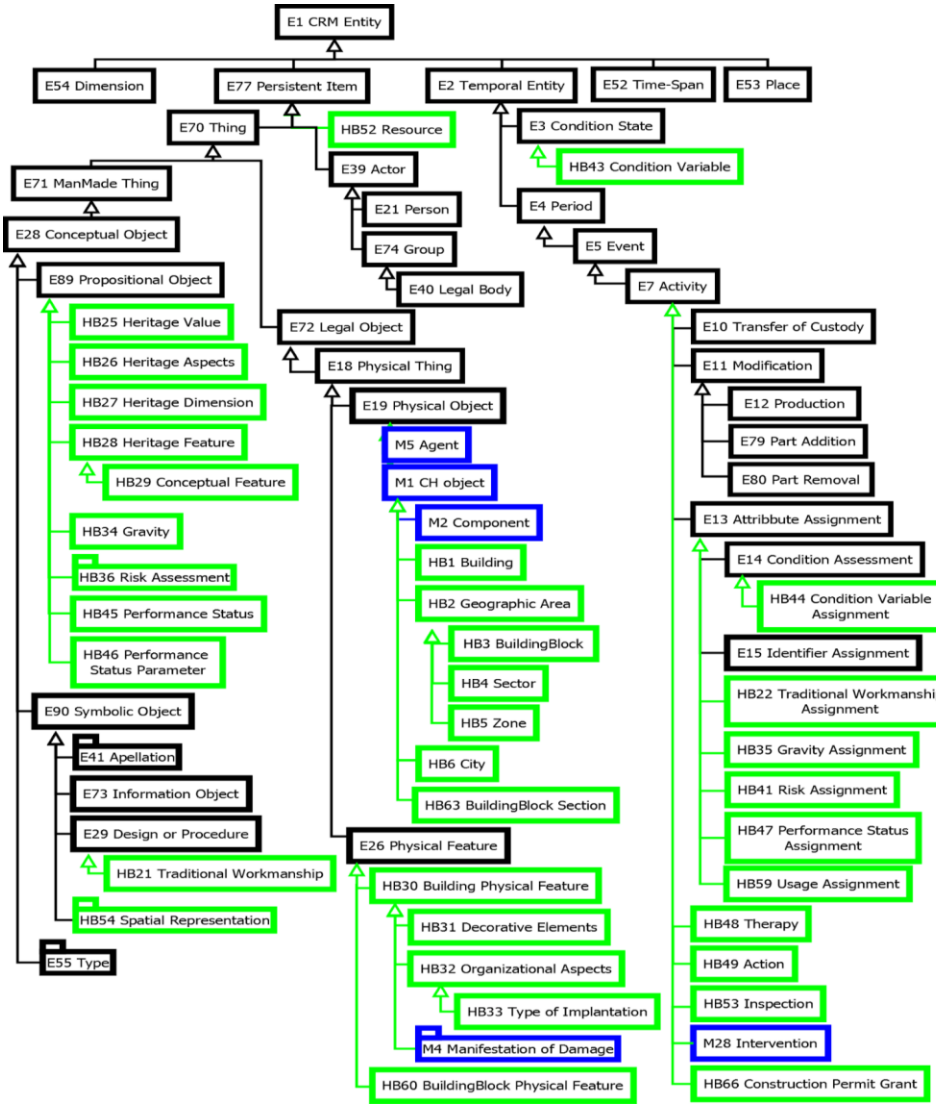


Fig.4.12 Diagram depicting the main BCH-ontology classes and packages. Classes from CIDOC-CRM are in black, MONDIS in blue, Geneva-CityGML in yellow and new classes in green.

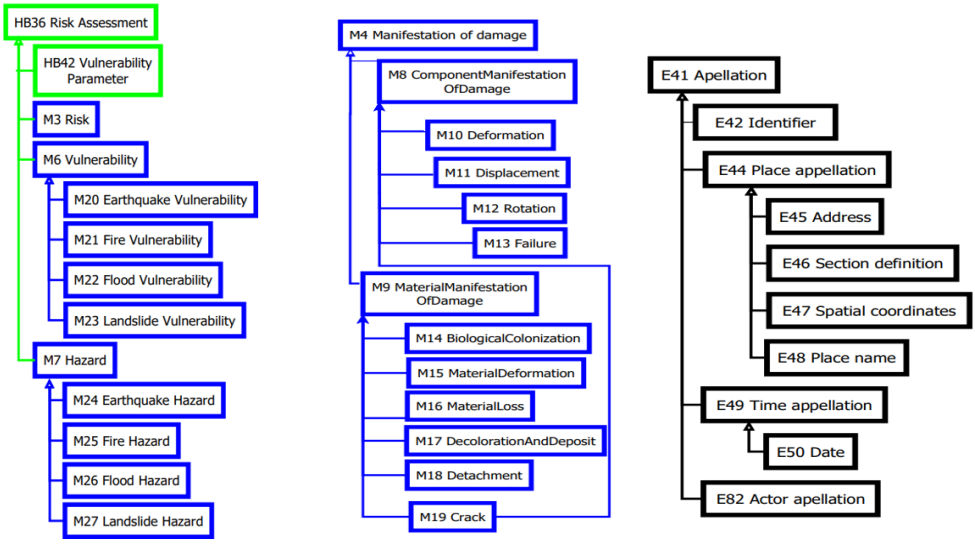


Fig.4.13 Diagram depicting the BCH-ontology packages: Risk, Damages and Apellation. Classes from CIDOC-CRM are in black, MONDIS in blue, Geneva-CityGML in yellow and new classes in green.

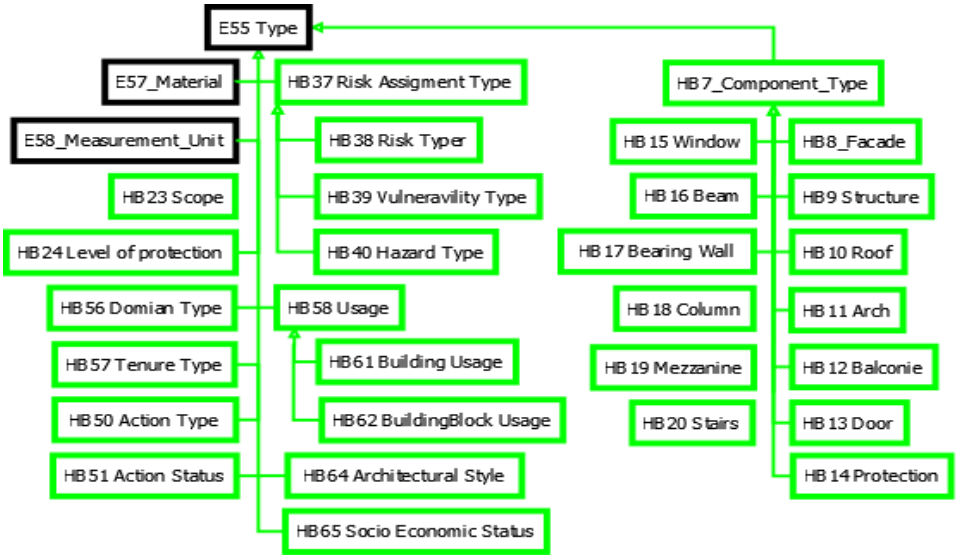


Fig.4.14 Diagram depicting the BCH-ontology package: Type. Classes from CIDOC-CRM are in black, MONDIS in blue, Geneva-CityGML in yellow and new classes in green.

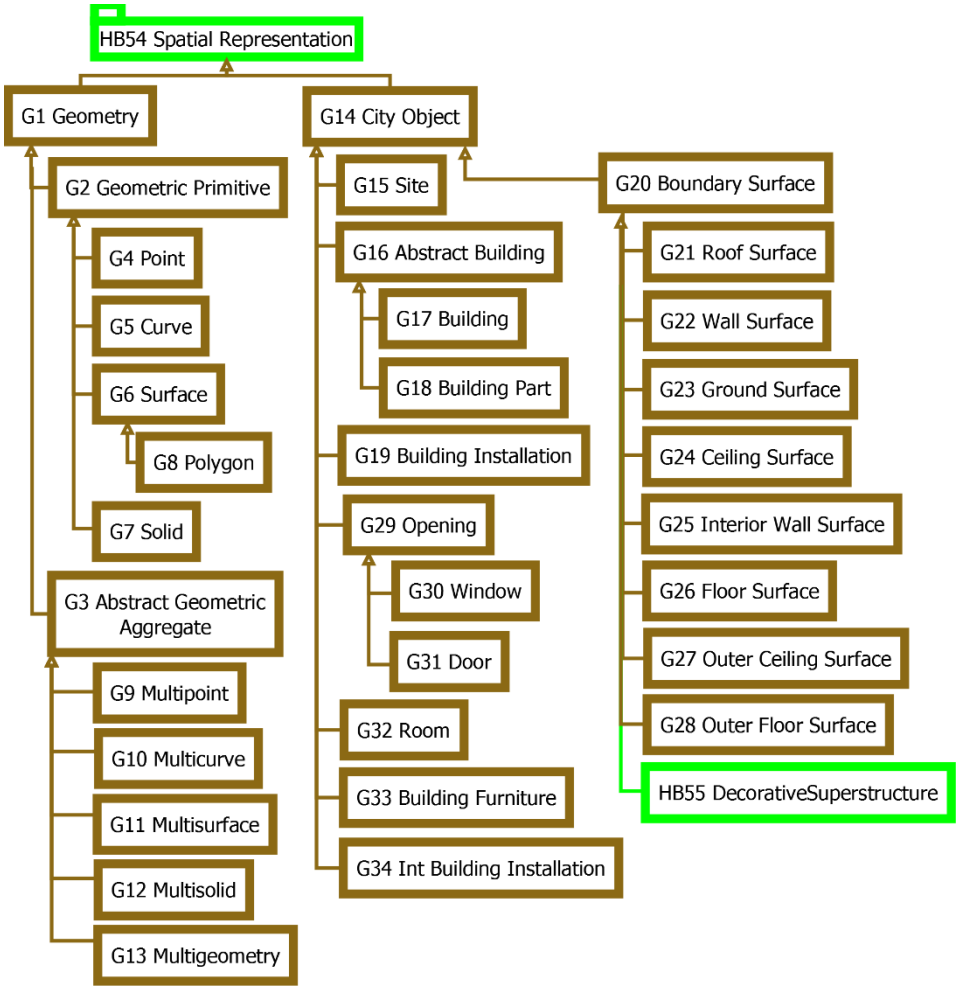


Fig.4.15 Diagram depicting the BCH-ontology packages: Spatial representation. Classes from CIDOC-CRM are in black, MONDIS in blue, Geneva-CityGML in yellow and new classes in green.

4.3.3 Naming convention

The naming of CIDOC-CRM classes can be translated into any language as long as the identifying codes are preserved. The CIDOC-CRM identification codes for classes start with the prefix 'E' which stands for 'entity', followed by a sequential number and the name of the class [168].

CIDOC-CRM properties use the prefix 'P'. Geneva-CityGML, MONDIS and new classes and properties are named respectively 'G', 'PG', 'M', 'PM', 'HB', and 'PHB'. HB stands for 'historical buildings'. Each word of the class name is followed by a blank space and starts with upper case, except articles and prepositions. Properties are written with lower case.

4.3.4 CIDOC-CRM basic structure

The CIDOC-CRM ontology groups the classes into two super-classes: "E2 Temporal Entities" and "E77 Persistent Item." "E2 Temporal Entity" instances happen over a limited continuous period of time and have a location. This class includes the following: periods, events, the condition state of a heritage unit, and activities in general. The "E77 Persistent Item" class encompasses those classes whose identity remains unchanged for a longer period of time. The class encompasses either physical entities, such as people, animals or material things, or conceptual entities such as ideas, concepts, products of the imagination or common names. We also adopted this structure as the root for the BCH-ontology.

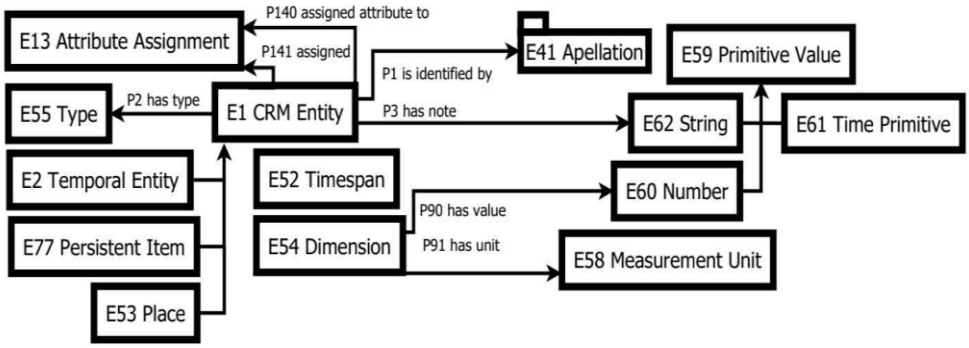


Fig.4.16 Diagram depicting the CIDOC-CRM basic structure.

The “E53 Place”, “E52 Timespan” and “E54 Dimension” classes represent location, temporal features and measurements. Dimensions have value and measurement units, which are represented by the “P90 has value” and “P90 has unit” properties. Every “E1 CRM Entity” instance has appellation, type, notes and attributes. Appellation identifies the entity. The class “E55 Type” supports the classification of entities and the assignment of qualitative values; the class “E62 String” can be used to record comments regarding the entity; and the “E13 Attribute Assignment” class allows to assign attributes such as identifiers, condition, measurements or types.

Primitive values as numbers, string and time are enclosed in the “E59 Primitive Value”, which, together with the “E1 CRM Entity” class, are at the root of the CIDOC-CRM ontology.

4.3.5 The BCH-ontology and the preventive conservation approach

An important goal of the BCH-ontology is to be able to represent the PC approach. In this section we go over all the preventive conservation phases and highlight the BCH classes relevant to each phase.

Analysis In the analysis phase, information regarding heritage entities is collected through the “M1 CH Object” class; from now on heritage entities are referred as cultural heritage objects (CH objects). CH objects can be: components, a single building, bigger geographic areas (building blocks, sectors, zones) or the whole city. Single buildings are represented using the “HB1 Building” class. The “HB2 Geographic Area” class contains the “HB3 Building Block”, “HB4 Sector” and “HB5 Zone” subclasses. The city is represented by the “HB6 City” class.

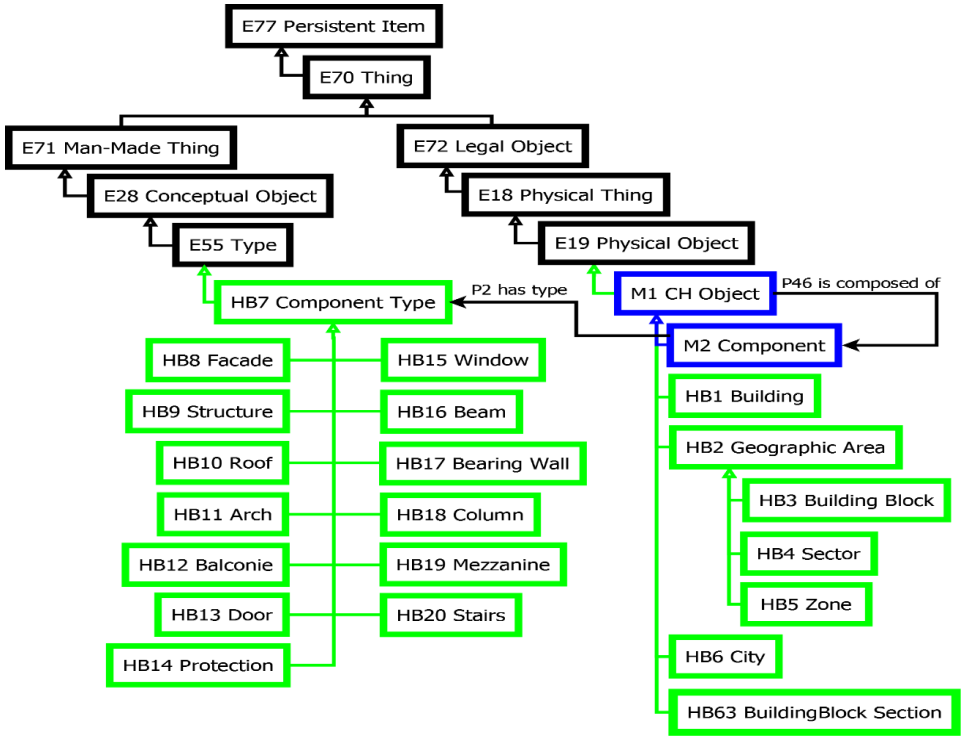


Fig.4.17 Diagram depicting the Analysis phase classes: CH Object and Component classes.

CH Objects have constitutive elements, represented with the "M2 Component" class. MONDIS provides a list of 122 classes and subclasses to represent components. This classification is too complex for our case study and still does not accommodate all required concepts. For this reason we have created a simpler typology under the "HB7 Component Type" class which is a subclass of "E55 Type." The "P46 is composed" property is used to show the relationship between CH objects and components.

Materials and traditional techniques used in components are also gathered. "E57 Material" and "HB21 Traditional Workmanship" classes are used for this purpose. The latter is included as subclass of the "E29

Design or Procedure" class. The "P127 has broader term" property allows to have classifications of materials. The "P45 consist of" property links components with their materials. The "P68 foresees use of" property links the traditional workmanship with the component material. The "HB21 Traditional Workmanship Assignment" class has been created under the "E13 Attribute Assignment" class. Properties "P140 assigned attribute to" and "P141 assigned" are used to link the traditional workmanship with the CH object.

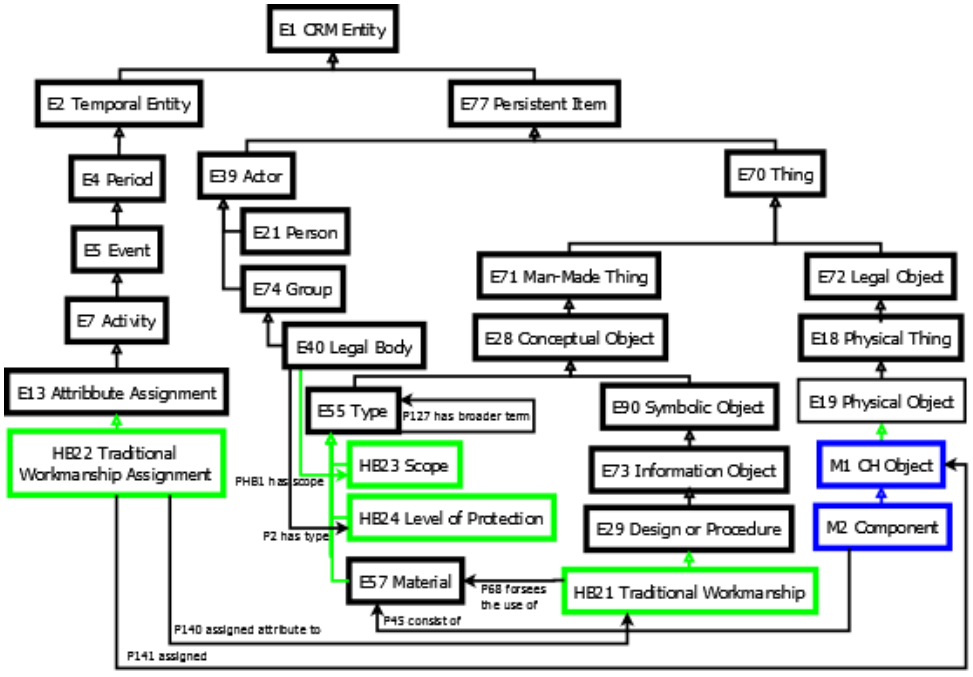


Fig.4.18 Diagram depicting the Analysis phase classes: material, traditional workmanship and legal body.

Legal protection is represented by the "E40 Legal Body" class. "HB23 Scope" and "HB24 Level of Protection" classes are added to the "E55 Type" class. "PHB1 has scope" and "P2 has type" properties link the "E40 Legal body" class with the scope and the level of protection.

CH Objects have heritage values associated with one or more heritage aspects and dimensions according to the Nara Document on Authenticity (Van Balen 2008). The “HB25 Heritage Value”, “HB26 Heritage Aspect” and “HB27 Heritage Dimension” subclasses are added to the “E89 Propositional Object” class, which comprises intangible items that represent propositions about real or imaginary things and that are documented as single units. The “P67 refers to” property is used to link the heritage value to the CH object, and aspects and dimensions to the heritage value. The “P3 has note” property can be used to add a description of the heritage value. Instances of heritage aspects are: Form and design, Materials and substance, Use and function, Tradition, Technique and workmanship, Location and setting, and Spirit and feeling. The heritage dimensions instances are: Artistic, Historic, Social and Scientific.

A heritage value is set according to several valuable features represented by the “HB28 Heritage Feature” class. Heritage features can be represented by the “E26 Physical Feature” or “HB29 Conceptual Feature” classes which are related with the “P67 refers to” property. The “E26 Physical Feature” class comprises identifiable features that are physically attached in an integral way to particular physical objects. The “HB29 Conceptual Feature” class represents immaterial features related to a persistent item. The “P67 refers to” property also links the heritage value and features with the physical object.

When the heritage unit refers to a building, some physical features are already established, such as “HB30 Building Physical Feature”, “HB31 Decorative Element” and “HB32 Organizational Aspect” classes. “HB33 Type of implantation” is a subclass of the “HB32 Organizational Aspect” class. “PHB2 has courtyard” and “PHB3 has orchard” properties link the “HB32 Organizational Aspect” class with its value. Other physical features have to be defined for different heritage units, for example for the “HB60 Building Physical Feature” class.

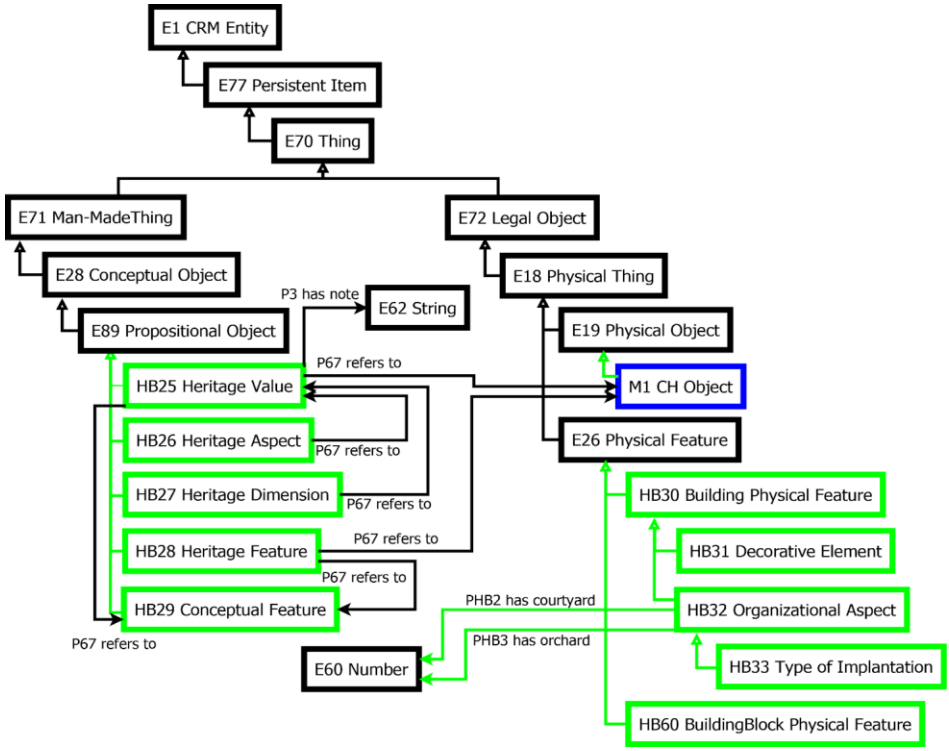


Fig.4.19 Diagram depicting the Analysis phase classes: heritage values and heritage features.

Other collected information regarding valuable features are Gravity, Risk, and Condition represented by the "HB34 Gravity", "M3 Risk" and "E3 Condition State" classes. Gravity is composed of damages (disturbances) and deterioration agents. The "M4 Manifestation of Damage" class from the MONDIS ontology is positioned under the "HB30 Building Physical Feature" class. MONDIS classifies damages present in a component or in the material covering the component (Fig.4.20). Deterioration agents are instances of the "M5 Agent" class which is a subclass of "E19 Physical Object." The property "PHB4 has agent" relates damages to deterioration agents. The "PHB5 has damage" property relates gravity to damages. The property "P56 bears feature" links

damages with the CH object. The “HB35 Gravity Assignment” class and properties “P140 assigned attribute to” and “P141 assigned” are used to link gravity with the heritage value.

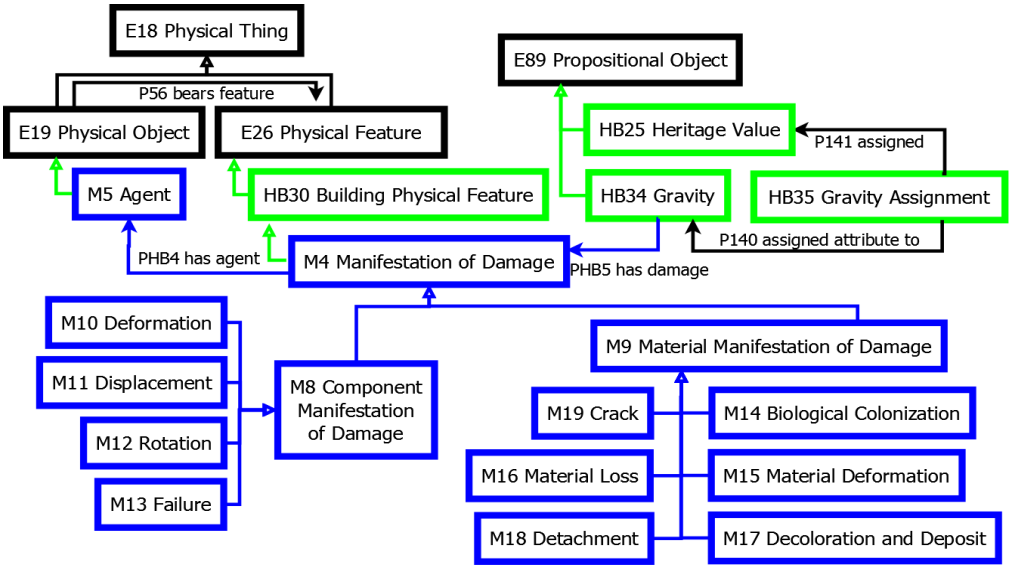


Fig.4.20 Diagram depicting the Analysis phase classes: manifestation of damage.

Risk is computed taking into account threats and vulnerability. The MONDIS ontology provides the “M3 Risk” and “M6 Vulnerability” classes while threats are represented with the “M7 Hazard” class. The “HB36 Risk Assessment” class is created as a subclass of “E28 Conceptual object” class and comprises risk, vulnerability and hazard concepts. “HB36 Risk Assessment” classes can have a quantitative or qualitative value.

Qualitative values are added using the “E2 Type” and “HB37 Risk Assessment Type” classes. In this case the qualitative values for the risk assessment classes are: ‘Low,’ ‘Medium,’ and ‘High’. If each class has different qualitative values the “HB38 Risk Type,” “HB39 Vulnerability

Type," and "HB40 Hazard Type" classes will be used. A quantitative measure can be added through the "E54 Dimension" class and the "P43 has dimension" property.

"MP1 refers to hazard" property links hazard with risk. Risk is related to the heritage value through the "HB41 Risk Assignment" class and "P140 assigned attribute to" and "P141 assigned" properties. "MP2 is subject to" property links vulnerability with hazard.

MONDIS also further classifies vulnerabilities and hazards with respect to earthquakes, fire, floods and landslides. To compute the vulnerability a new class "HB42 Vulnerability Parameter" is created. These parameters are accompanied by a weight, since not all the parameters have the same importance. To this end the "PHB6 has weight" property has also been added. The "PHB7 has parameter" property relates parameters to vulnerability.

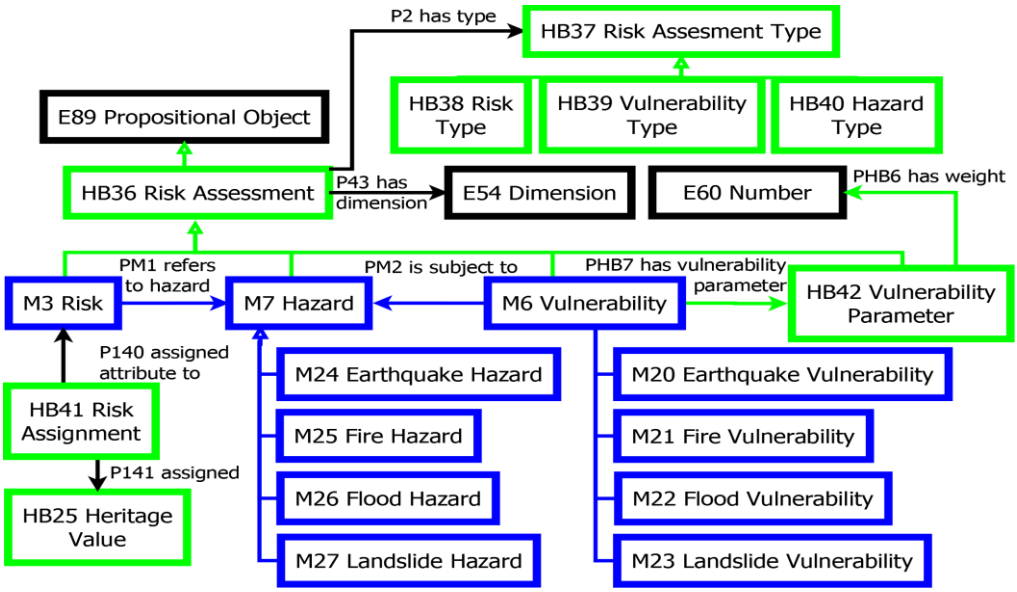


Fig.4.21 Diagram depicting the Analysis phase classes: risk, vulnerability, hazard.

The condition is recorded with the “E3 Condition State” class, through a list of variables represented by the “HB43 Condition Variable” class. The “HB44 Condition Variable Assignment” class is created under the “E14 Condition Assessment” class and links condition variables with their value and the weight through the “PHB8 has condition value” and “PHB9 has condition weight” properties. The “PHB10 has condition variable” property links the condition variable to the assignment. The condition variable assignment is linked to the general condition with the “P5 consist of” property; general condition is linked to the heritage value with the “PHB11 refers to value” property.

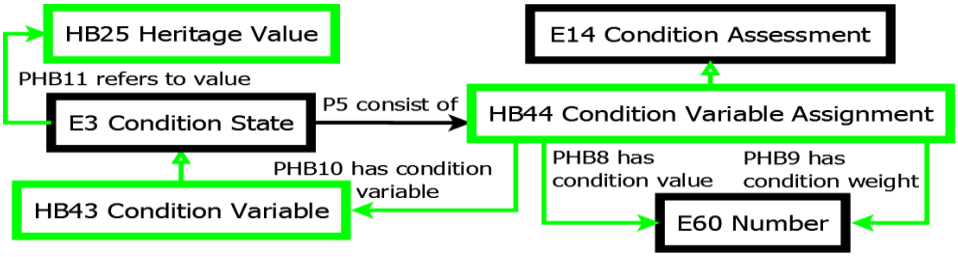


Fig.4.22 Diagram depicting the Analysis phase classes: condition state.

Diagnosis In the diagnosis phase, the “HB45 Performance Status” and “HB46 Performance Status Parameter” classes are added under the “E28 Conceptual Object” class. The effect of consequential damage, the speed of deterioration, the relative importance of damages and the alterations are instances of the performance status parameters. The “PHB12 has parameter” property links the performance status with its parameters.

The “PHB13 has max limit” and “PHB14 has min limit” properties establish thresholds for the performance status parameters. Quantitative values to the performance status and each parameter are assigned through the “E54 Dimension” class and the “P43 has dimension” property. The “HB47 Performance Status Assignment” class links the performance status with the heritage value.

According to the performance status a therapy with some actions is suggested. The “HB48 Therapy” class is created under the “E7 Activity” class. The “PHB15 has therapy” property links the suggested therapy with the performance status. The “PHB16 has suggested action” property links the therapy with the suggested actions. Actions in general are represented by the “HB49 Action” class.

The “HB50 Action Type” and the “HB51 Action Status” classes are created under the “E55 Type” class. Instances of the “HB50 Action Type” class are curative or preventive (direct, indirect). The status of the action can be “suggested action” and “executed action.” The “PHB17 has status” property links the action status to the suggested action. The type of action is assigned through the “P2 has type” property.

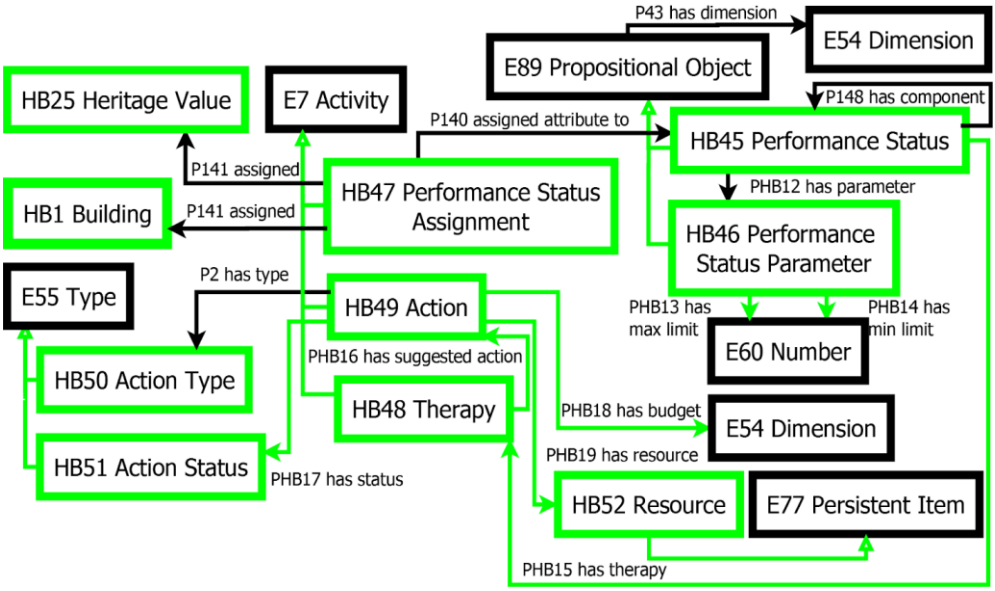


Fig.4.23 Diagram depicting the classes of the Diagnosis phase.

The “PHB18 has budget” and “PHB20 has resource” properties associate a budget and the resources needed for the execution of the suggested

action. The budget can be represented by the “E97 Monetary Amount” class. The “HB52 Resource” class is created under the “E77 Persistent Item” class.

Therapy During the therapy phase an intervention is executed. The MONDIS “M28 Intervention” class is used to keep track of the suggested actions used in the intervention. The suggested therapy is linked to the intervention through the “PHB20 has intervention” property.

An individual action used during the intervention is recorded through the “HB49 Action” class. The “PHB21 has intervention action” property links the intervention with the action. The “HB51 Action Status” class instantiated as “executed action” means that the suggested therapy action was executed in the intervention.

The “MP3 is eliminated by intervention” and “MP4 is repair of damage” properties link the agent and damage that are tackled by the intervention.

Control The control phase ends with one or more inspections to verify whether the actions reached the conservation objective. The “HB53 Inspection” class is created under the “E7 Activity” class. The “PHB22 requires further inspections” property means that more control activities are required. The “PHB23 conservation objective reached” property points out whether the conservation objective has been reached. Additional notes can be added through the inherited property “P3 has note.” The therapy is linked to the inspection through the “PHB24 has inspection” property.

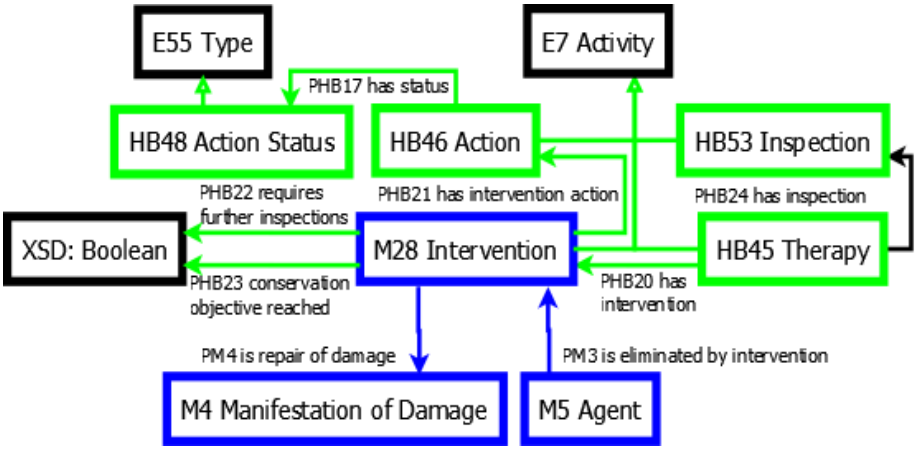


Fig.4.24 Diagram depicting the classes of the Therapy and Control phases.

4.3.6 The BCH-ontology and spatial representation

In this section we describe the employed classes from the ontological version of the CityGML standard developed by the University of Geneva [169]. These classes are used to represent spatial information.

In order to represent geometries from the different objects the “G1 Geometry” class is used. Geometries can be represented by the “G2 Geometric Primitive” class or the “G3 Abstract Geometric Aggregate” class. Geometric primitives are classified into the “G4 Point,” “G5 Curve,” “G6 Surface,” and “G7 Solid” classes. Surfaces are classified into the “G8 Polygon” class. Abstract geometric aggregates are classified into the “G9 Multipoint,” “G10 Multicurve,” “G11 Multisurface,” “G12 Multisolid,” and “G13 Multigeometry” classes.

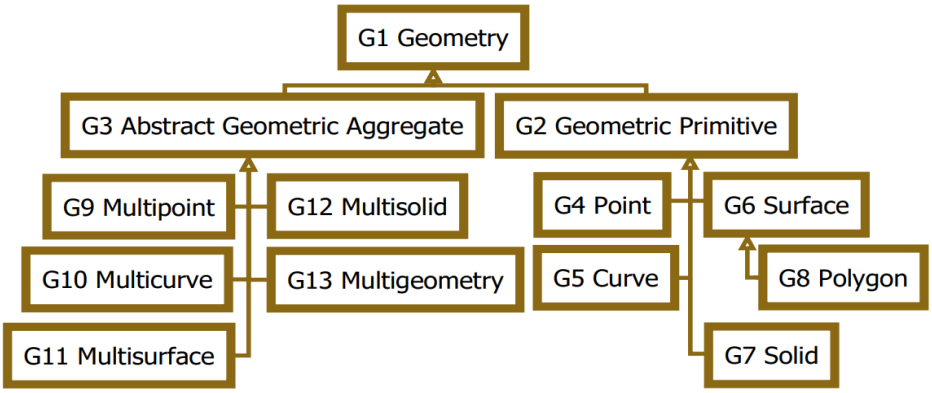


Fig.4.25 Diagram depicting the geometry classes for spatial representation.

The “G14 City Object” class contains all the CityGML standard classes except the “G1 Geometry” classes. The “G1 Geometry” and the “G14 City Object” classes are subclasses of the “HB54 Spatial Representation” which in turn is a subclass of the “E90 Symbolic Object” class.

The “G15 Site” class contains the “G16 Abstract Building” class which comprises the “G17 Building” and “G18 Building Part” classes. The “PHB25 has geographical representation” is used to link “HB1 Building” “M2 Component” classes with their spatial representations.

The CityGML standard has different LoDs to represent its elements. The first level LoD0 uses 2.5-dimensional surfaces (elevation models) to represent the footprint and the roof edge of a building. Surfaces are represented with the “G11 MultiSurface” class. The “PG1 lod0 footprint” and “PG2 lod0 roof edge” properties are used to link the abstract building to the multisurface.

The outer shell of the building is represented in the second level of detail LoD1 as a block by the “G7 Solid” class. The “PG3 lod1 solid” property links the solid with the building.

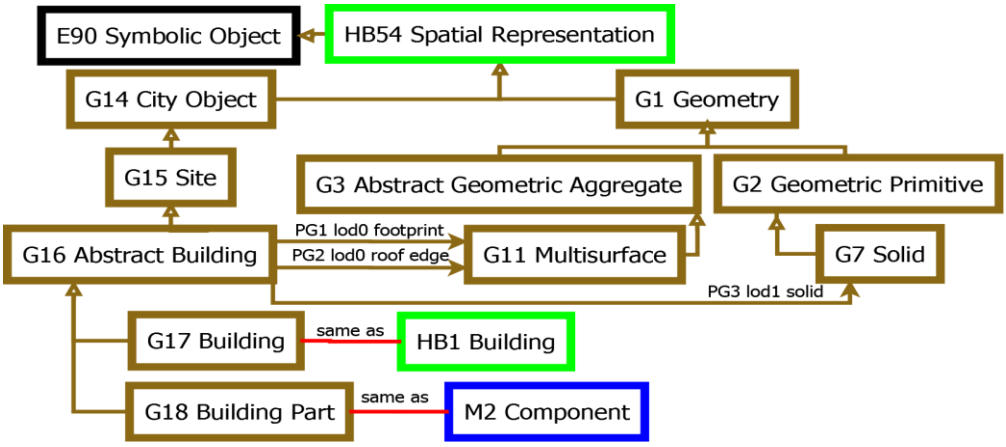


Fig.4.26 Diagram depicting the spatial representation classes for buildings and their components.

The representation of architectural details, like roof overhangs, columns, or antennas is made in in the level of detail LoD2 through the "G19 Building Installation" class. The "PG4 outer building installation" property links the abstract building with the building installation. The geometry of architectural details is represented using multisurfaces. The "G20 Boundary Surface" class comprises "G21 Roof Surfaces," "G22 Wall Surface," "G23 Ground Surface," "G24 Ceiling Surface," "G25 Interior Wall Surface," "G26 Floor Surface," "G27 Outer Ceiling Surface," "G28 Outer floor surface" and "HB55 DecorativeSuperstructure" classes. Building installations are linked to boundary surfaces through the "PG5 bounded by" generic property and boundary surfaces are linked to multisurfaces through the "PG6 lod2 multisurface" property.

Openings are represented in LoD3 by the "G29 Opening" class and the "G30 Door" and "G31 Window" subclasses. The geometry is represented by multisurfaces through the property "PG7 lod3 multisurface". An opening in a boundary surface is represented using the property "PG8 opening".

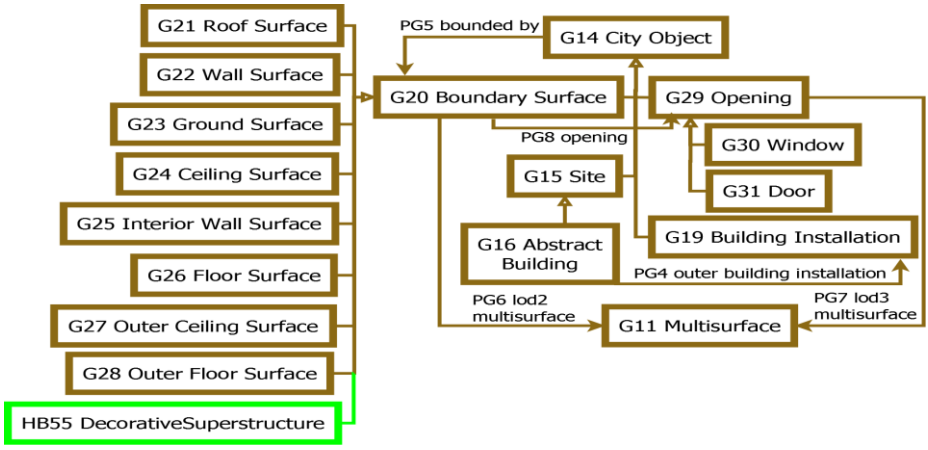


Fig.4.27 Diagram depicting the spatial representation classes for surfaces, openings and building installations.

Elements of the building interior such as rooms, furniture, and interior building installations are represented in LoD4 through the "G32 Room," "G33 Building Furniture" and "G34 Int building installation" classes. Room geometry is represented by solids or multisurfaces through the "PG9 lod4 solid" and "PG10 lod4 multisurface" properties. A boundary surface is linked to a room with the "PG5 bounded by" generic property. Furniture and interior building installations are represented using any set of geometries through the "PG11 lod4 geometry" generic property.

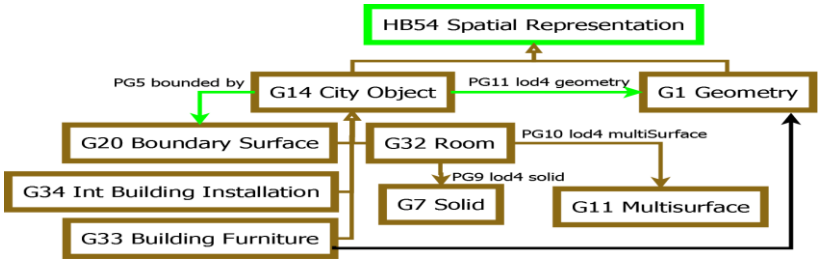


Fig.4. 28 Diagram depicting the spatial representation classes for interior building installations, building furniture and rooms.

4.3.7 The BCH-ontology and temporal representation

Phenomena that happen over a limited period of time are represented by the "E2 Temporal Entity" class. Periods of time are described with the "E52 Time-Span" class. The "P4 has time-span" property relates a period of time with the temporal entity.

The "P81 ongoing throughout" property links the time span with the "E61 Time Primitive" class. Time primitives are not further developed by the CIDOC-CRM ontology since there are specific ontologies for this, such as the time ontology developed by W3C and OGC [170]. For the purpose of this research, we will assume the "E61 Time Primitive" class is defined by the W3C/OGC time ontology.

Other important properties are "P115 finishes" and "P116 starts" which define the beginning and end of temporal phenomenon. Maximum and minimum durations are represented using the "P83 had at least duration" and "P84 had at most duration" properties, which link "E52 Time-Spans" with the "E54 Dimension" class. The "P82 at some time within" property describes a period of time which happened at some point during a longer period of time. This property is very useful in case of uncertainty.

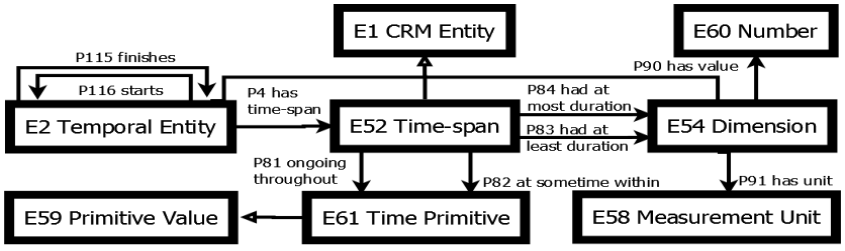


Fig.4.29 Diagram depicting the BCH-ontology temporal classes.