Linked Conservation Data

LCD Modelling Working Group

Overview of current conservation and restoration models

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Introduction

The purpose of the current document is to review existing semantic models of the *Conservation and Restoration* (CnR) domain. Specifically, we studied and present our findings for the following models (the models are presented following an oldest-first chronological order):

- *CRMcr* model, which was proposed in the context of PARCOURS project. It is specialised in CnR of tangible *Cultural Heritage* (CH).
- *CPM* (Conservation Process Model) model, which has been developed as an independent model, also aiming at providing integration of geometrical and non-geometrical information within *building information modeling* (BIM). In this context, it has been deployed in *Autodesk Revit*[1], a BIM software. CPM is specialized in CnR of immovable CH and particularly CnR of historical buildings.
- *EAMENA model,* which was proposed in the context of the EAMENA project. It is specialized in CnR of immovable CH and particularly CnR monuments, buildings and sites.

The study of the models has been conducted according to six axes: (i) CnR intervention, (ii) CnR intervention plan, (iii) deterioration process/effect, (iv) risk and risk assessment, (v) measurement, (vi) object technology (including transformation of objects and buildings). Those axes were chosen to reflect the basic types of CnR information.

The purpose of the study is to i) record the coverage of these models for CnR data, ii) identify their inaccuracies and contradictions and iii) work on possible concept extensions and property paths of the CIDOC CRM specialized for CnR data representation.

1. Conservation and Restoration (CnR) Intervention

1.1. Modeling Approach

1.1.1. PARCOURS Project (CRMcr Model)

CRMcr introduces the class *C22_Intervention* as a subclass of the CIDOC CRM class *E7_Activity*. *C22_Intervention* has two subclasses: i) *C23_Conservation* which has the subclasses *C24_Preventive_Conservation* and *C26_Remedial_Conservation* and ii) *C29_Restoration*.

According to the CRMcr model, a deterioration process (*S18_Alteration*) needs an intervention (*C22_Intervention*). The deterioration process affects a certain area of the *conservation object* (*C15_Altered_Area*). CRMcr class *C15_Altered_Area* represents the result of the deterioration process (deterioration effect).

[1] https://www.autodesk.com/education/free-software/revit

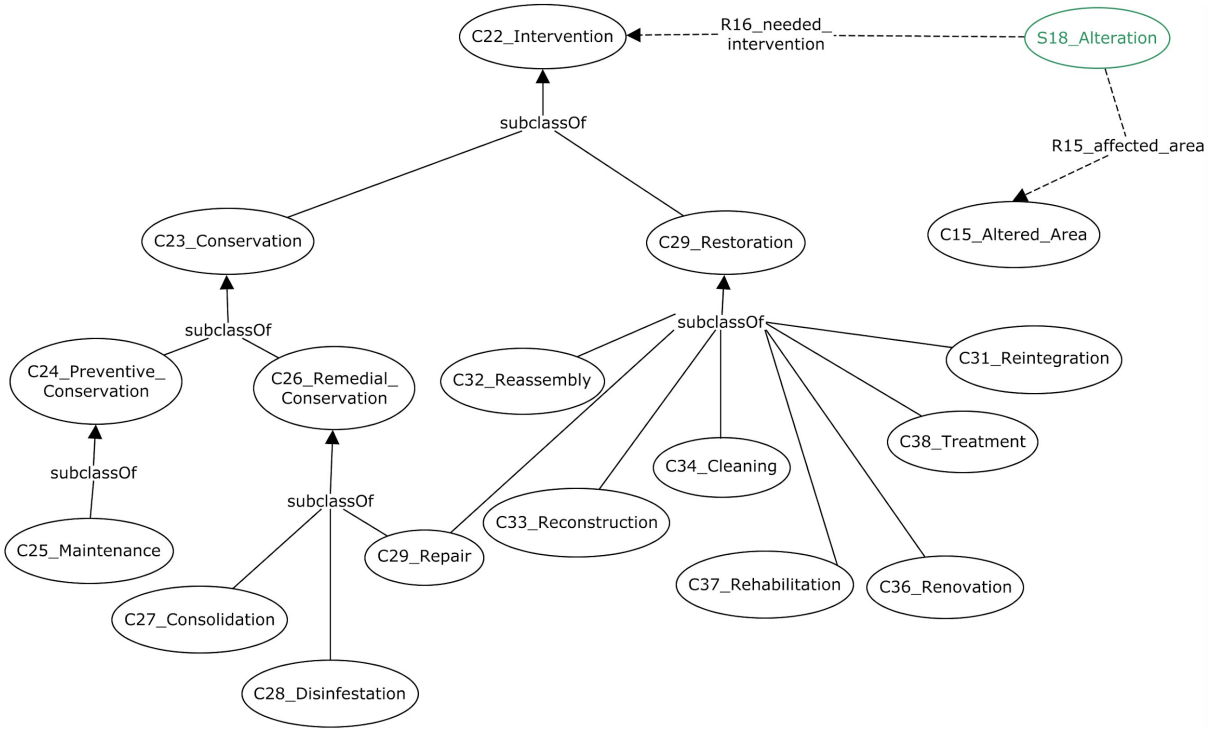

Image 1: Concept map of a *CnR intervention* with classes and object properties from CRMcr.

1.1.2. Sapienza (CPM Model)

CPM model introduces the class *Ecpm5_Surfaces_Conservation_Executive_Planning* as a subclass of the CIDOC CRM class *E7_Activity*. *Ecpm5_Surfaces_Conservation_Executive_Planning* has six subclasses which represent specific CnR interventions. However, it appears to represent the *planning* of an intervention rather than *the execution of* an intervention. Therefore, it is further discussed in section 2 (see *2. Conservation and Restoration (CnR) Intervention Plan*).

1.1.3. EAMENA

EAMENA appears to represent *CnR intervention* with the CIDOC CRM class *E11_Modification*.

According to the EAMENA model, a conservation object (*E24_Physical_Man-Made_Thing*) has been modified by a modification activity (*E11_Modification*). The modification activity has been conducted in a certain time-span (*E52_Modification_Time-Span*), using a modification technique (*E55_Technique*) and material (*E57_Material*). Furthermore, the modification activity has a specific type (*E55_Modification_Type*) and some note (*E62_Note*) assigned to it.

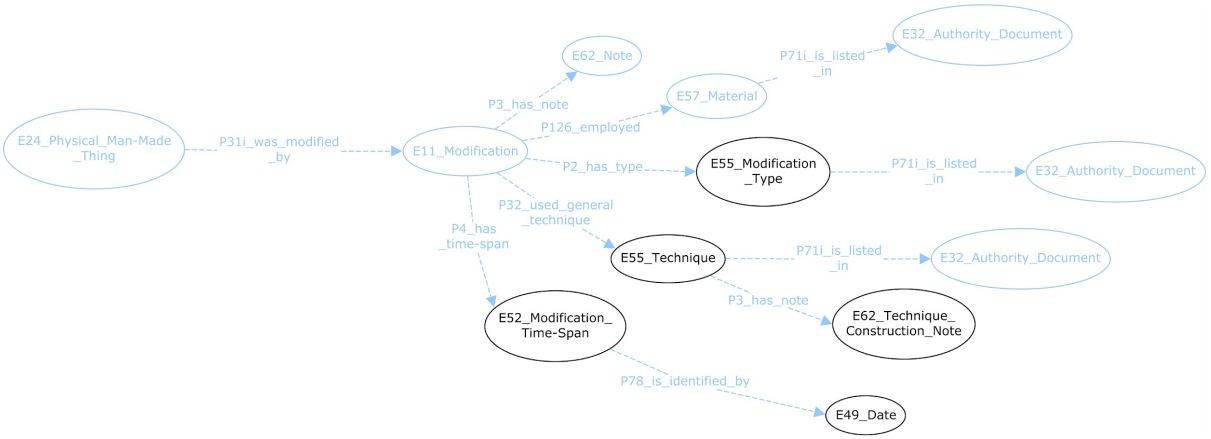

Image 2: Concept map of a *CnR intervention* with classes and object properties from EAMENA.

1.2. Discussion

Taking into account each model's approach regarding the representation of CnR intervention, we formulated a concept map that covers the same field of interest using classes and object properties from CIDOC CRM and CRMsci.

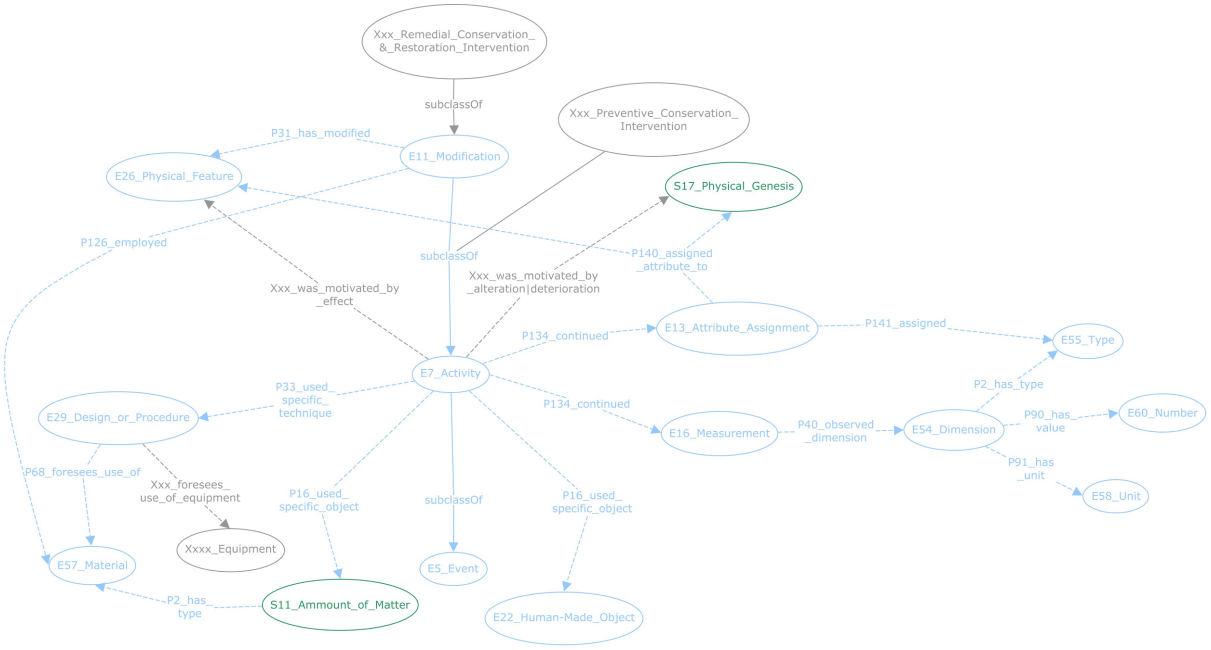

Image 3: Concept map of a *CnR intervention* with classes and object properties from CIDOC CRM and CRMsci.

CRMcr has classes which represent CnR interventions mapped to the CIDOC CRM class *E7_Activity.* The CIDOC CRM *E7_Activity* class is too generic to represent the concept of CnR intervention. We could discuss the introduction of specialised classes for representing the three main categories of CnR interventions (*preventive conservation*, *remedial conservation*, *restoration*). These subclasses would be useful for a domain-specific ontology of the CnR domain. For example, we can introduce the class *Xxx_Remedial_Conservation_and_Restoration_Intervention* as a subclass of CIDOC CRM

class *E11_Modification* and the class *Xxx_Preventive_Conservation_Intervention*, as a subclass of CIDOC CRM *E7_Activity.*

CnR intervention could be linked to the result (*E25_Physical_Feature*) of a deterioration process (*S17_Physical_Genesis*), using the property *P17_was_motivated_by*. Furthermore, we could discuss the introduction of the following new properties (i) *Xxx_was_motivated_by_alteration|deterioration* (with domain the CIDOC CRM class *E7_Activity*, and range the CRMsci class *S17_Physical_Genesis*), and (ii) *Xxx_was_motivated_by_effect* (with domain the CIDOC CRM class *E7_Activity*, and range the CIDOC CRM class *E26_Physical_Feature*), as sub-properties of the CIDOC CRM property *P17_was_motivated_by.* In this way we can represent the specific purpose of the CnR intervention - what deterioration process or effect it treats-prevents.

Furthermore, as the CPM model suggests, it is necessary to represent the fact that a certain feature or process is identified as deterioration (effect/process), or more generally as “undesirable”, according to expert assessment. Therefore, we present a potential property path using CIDOC CRM classes (*E13_Attribute_Assignment, E55_Type, E25_Physical_Feature, S17_Physical_Genesis*) and object properties (*P134_continued, P140_assigned_attribute_to, P141_assigned*).

Regarding the specific material and equipment which are used during an intervention, the CRMcr model does not highlight them. As we will see in section 2, the representation of general technique, material type and equipment type is achieved through the mapping of CRMcr classes that represent the concepts of *material*, *technique* and *equipment* to the class *C10_Procedure* (the plan that intervention activity executes). However, we suggest that the full representation of the intervention activity, including the specific materials, techniques and equipment that have been used, is equally useful. Thus, we present a potential property path (see Image 3) using CIDOC CRM and CRMsci classes (*S11_Ammount_of_Matter, E29_Design_or_Procedure and E22_Human-Made_Object*) and object properties (*P16_used_specific_object, P33_used_specific_technique*).

2. Conservation and Restoration (CnR) Intervention Plan

2.1. Modeling Approach

2.1.1. PARCOURS Project (CRMcr Model)

CRMcr introduces the class *C44_Conservation_Proposal*, though its superclass (from CIDOC CRM) is not mentioned in the relevant literature. Additionally, CRMcr introduces the class *C10_Procedure*, which is a subclass of the CIDOC CRM class *E29_Design_or_Procedure.* The aforementioned classes (*C44_Conservation_Proposal, C10_Procedure*) appear to represent the intervention plan executed by an intervention activity.

According to the CRMcr model, a conservation proposal (*C44_Conservation_Proposal*) initiates an intervention (*C22_Intervention*). The intervention (*C22_Intervention*) follows a procedure (*C10_Procedure*) which uses some technique(s)

(C21_Intervention_Technique), instrument(s) (*C12_Instrument*) and material(s) (*E57_Material*) (see Image 4).

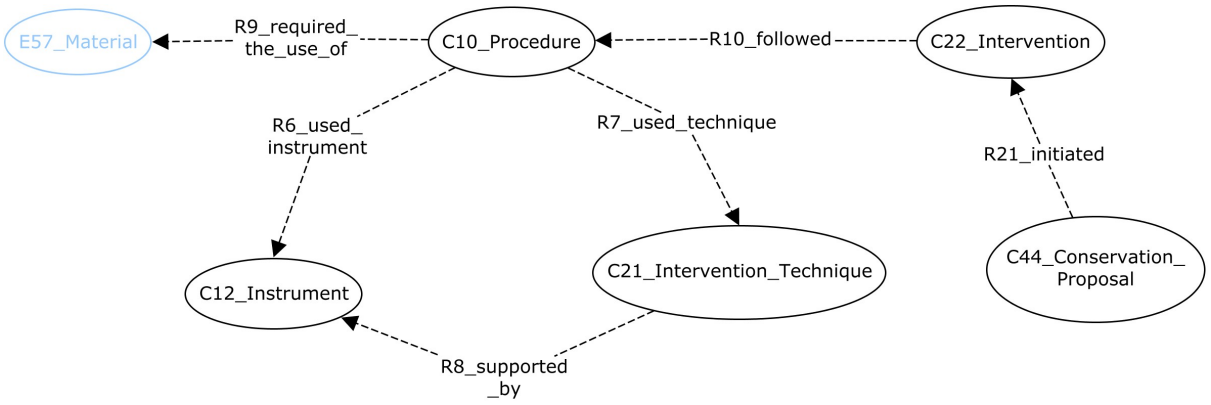

Image 4: Concept map of a *CnR intervention plan* with classes and object properties from CRMcr.

2.1.2. Sapienza (CPM Model)

CPM introduces the class *Ecpm5_Surfaces_Conservation_Executive_Planning* as a subclass of the CIDOC CRM class *E7_Activity*. The aforementioned class appears to represent the activity of planning of some intervention and not its execution. *Ecpm5_Surfaces_Conservation_Executive_Planning* has six subclasses which represent specific CnR interventions.

According to the CPM model, a planning activity about the conservation of surfaces (*Ecpm05_Surfaces_Conservation_Executive_Planning*) is realised through different intervention planning activities (e.g. *Ecpm08_Consolidation*). Each intervention planning has a certain type (*Ecpm12_Intervention_Institutional_List*). This type implies the use of some material (*E57_Material*) and it is applied on a particular area (*EcpmA241_Surface_Area*) of a *conservation object* (*EcpmA1_Artifact_Entity*).

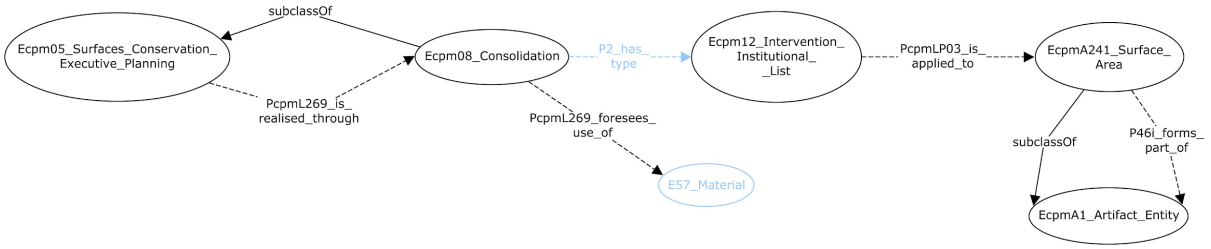

Image 5: Concept map of a *CnR intervention plan* with classes and object properties from CPM.

2.1.3. EAMENA

EAMENA appears to represent a *CnR intervention plan* with a once proposed CRM class *E100_Activity/Risk_Plan.* Currently this class is a proposal as part of the CRMsoc extension (*socE2_Activity_Plan*).

According to EAMENA representation, a plan (*E100_Activity/Risk_Plan*) is motivated by a potential risk of a *conservation object* (*XX1_Potential_(Risk)_State*). The plan has a certain type (*E55_Mitigation_Strategy_Type*) which (type) is presented in some document (*E32_Authority_Document*). Furthermore, the plan has a priority assignment

(*E13_Priority_Assignment*) of a certain type (*E55_Priority_Type*), which is listed in some document (*E32_Authority_Document*).

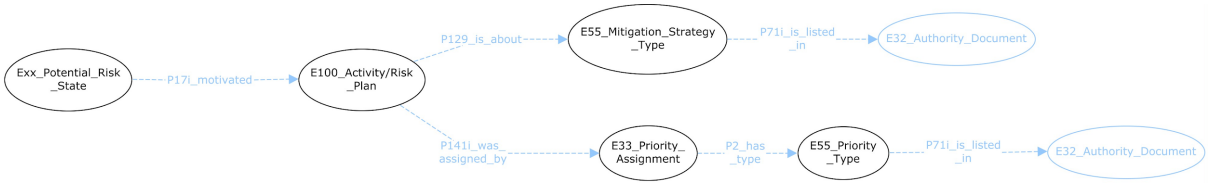

Image 6: Concept map of a *CnR intervention plan* with classes and object properties from CIDOC CRM, CRMsoc and EAMENA.

2.2. Discussion

Taking into account each model's approach regarding the representation of a CnR intervention plan, we created a concept map that covers this field of interest using classes and object properties from CIDOC CRM, CRMsci and CRMsoc.

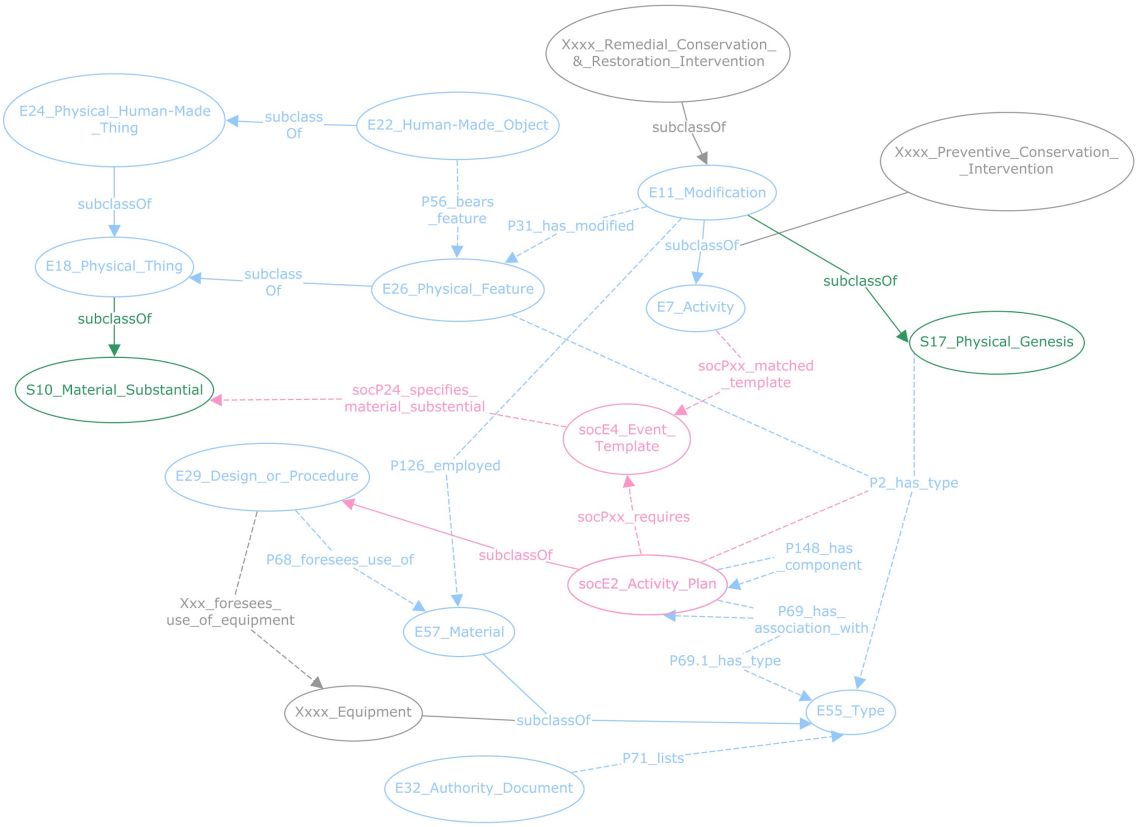

Image 7: Concept map of *CnR intervention plan* with classes and object properties from CIDOC CRM, CRMsci and CRMsoc.

The concept of *CnR intervention plan* is important for the knowledge representation of the CnR domain, as indicated by the implementation of all the three models. We recommend the use of the CRMsoc class *socE2_Activity_Plan* for the representation of CnR intervention plan.

Additionally, in the case of an intervention plan, it makes sense to represent the material(s) with the CIDOC CRM class *E57_Material* since we want to represent the type(s)

of material(s) that will be used during an intervention. This is not the case of *equipment* though. There is no object property that could connect the intervention plan with a certain type of equipment. As such, we could discuss the introduction of an object property (*Xxx_foresees_use_of_equipment*) and a class (*Xxx_Equipment*) that satisfies this need.

Furthermore, in the case of an intervention plan that is more complex and it actually consists of several sub-plans, we recommend the use of CIDOC CRM object property *P148_has_component*. In this way, we can represent the overall activity plan and its sub-plans or stages as well.

Additionally, we could discuss how an *socE2_Activity_Plan* should be correlated with *E25_Physical_Feature* and *E22_Human-Made_Object* to capture the case when the activity plan is designed to respond to specific damage on an object.

To indicate the sequence of instances of *socE2_Activity_Plan* the property *P69_has_association_with* can be used in combination with the property *P69.1_has_type* which can indicate that one instance of *socE2_Activity_Plan* can "follow" another. We should consider a controlled vocabulary where the correct instance of *E55_Type* can be provided. The implementation of ".1 properties" for the CRM is discussed elsewhere (http://new.cidoc-crm.org/Resources/modeling-properties-of-properties-in-the-cidoc-crm-rdf-encoding).

3. Deterioration Process/Effect

3.1. Modeling Approach

3.1.1. PARCOURS Project (CRMcr Model)

The CRMcr model represents the concept of *deterioration process* with the CRMsci class *S18_Alteration*. It also introduces the class *C15_Altered_Area* (and its subclasses *C48_Altered_Support* and *C49_Altered_Surface*) as a subclass of the CIDOC CRM class *E55_Type*. *C15_Altered_Area* represents the identifiable evidence of a deterioration process on a conservation object (in other words, the observed deterioration effect). Furthermore, CRMcr introduces the class *C14_Alteration_Factor* which represents the cause of alteration (deterioration process). Finally, CRMcr introduces the class *C4_Conservation_State* as a subclass of the CIDOC CRM class *E3_Condition_State*, which represents the overall condition state of a conservation object.

According to the CRMcr model, a *conservation object* (*C1_Cultural_Object*) is altered by an *alteration* (deterioration process) (*S18_Alteration*). The *alteration* has a *cause* (*C14_Alteration_Factor*) and it affects a certain *area* (*C15_Altered_Area*) of a *conservation object*. Finally, a *conservation object* has an overall *conservation state* (*C4_Conservation_State*).

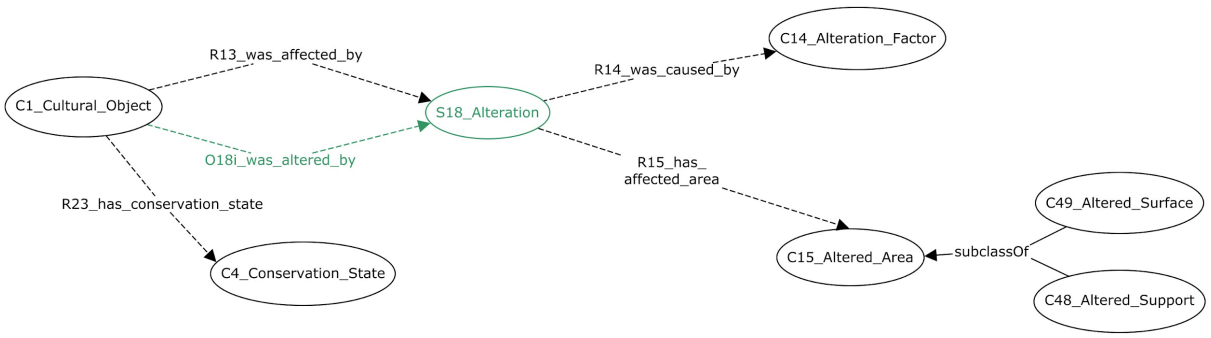

Image 8: Concept map of *deterioration process/effect* with classes and object properties from CRMcr.

3.1.2. Sapienza (CPM Model)

The CPM model represents the concept of the *deterioration effect* with the CIDOC CRM class *E3_Condition_State*. This class is linked to CPM class *Ecpm2_Decay_Phenomenon*, which is a subclass of CIDOC CRM class *E55_Type*, and it represents *types* of deterioration effects. Furthermore, CPM introduces the class *Ecpm1_Decay_Analysis* which appears to be a subclass of CIDOC CRM class *E14_Condition_Assessment* and represents the concept of analysis of *deterioration process*. Finally, CPM introduces the class *EcpmA241_Surface_Area* as a subclass of *E24_Phisical_Made_Man_Thing and* it represents the particular region of a conservation object, where a deterioration effect has been observed.

According to the CPM model, a *condition state* (*E3_Condition_State*) has a particular *deterioration effect type* (*Ecpm2_Decay_Phenomenon*). A *deterioration effect* is observed within a certain *area* (*EcpmA241_Surface_Area*) of a *conservation object* (*EcpmA1_Artifact_Entity*), during a deterioration analysis (*Ecpm1_Decay_Analysis*).

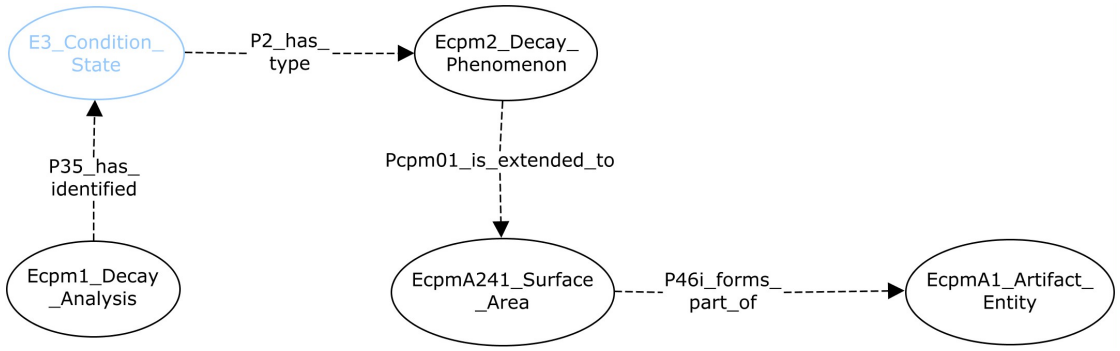

Image 9: Concept map of deterioration process/effect with classes and object properties from CPM.

3.1.3. EAMENA

The EAMENA model represents the concept of the *deteriorated state* of a conservation object with the class *E3_Damage_State*. It is not clear whether *E3_Damage_State* is a subclass of or equivalent to the CIDOC CRM class *E3_Condition_State*. Furthermore, EAMENA represents the stability and trend that a deterioration state may present with the class *E55_Damage_Stability_&_Trend*. It is not clear whether *E55_Damage_Stability_&_Trend* is a subclass of or equivalent to the CIDOC CRM class *E55_Type*. Also, EAMENA represents the *type* of a *deterioration effect* with the class

S9_Effect/Damage_Type. It is not clear whether *S9_Effect/Damage_Type* is a subclass of or equivalent to the CRMsci class *S9_Property_Type*. Finally, EAMENA also represents the event that has caused the deterioration effect with the class *E5_Disturbance_Event*. It is not clear whether *E5_Disturbance_Event* is a subclass of or equivalent to the CIDOC CRM class *E5_Event*.

According to the EAMENA model, a *conservation object* (*E24_Physical_Man-Made_Thing*) is subject to a condition *assessment procedure* (*E14_Condition_Assessment*), which identifies the conservation object's *deterioration state* (*E3_Damage_State*). The *deterioration state* presents a certain *stability and trend* (*E55_Damage_Stability_&_Trend*), and it has a certain *extent* (*E55_Damage_Extent_(Type)*) and *severity* (*E55_Damage_Overall_Severity/Classification*). The *extent* and *severity* of the deteriorated state are *measured* (*E16_Overall_Damage_Evaluation_(Measurement)*) and they are presented in some *document* (*E32_Authority_Document*). Additionally, the *deterioration state* has a specific *type* (*S9_Effect/Damage_Type*) which is assigned by an *observation procedure* (*S4_Damage/Disturbance_Event_Observation*). The *type* of the *deterioration effect* is presented in some *document* (*E32_Authority_Document*). Finally, the *deterioration state* is caused by some *event* (*E5_Disturbance_Event*), which has a certain *type* (*E55_Disturbance_Category*) and *time-span* (*E52_Time-Span*). The *assignment* (*E13_Cause_Assignment*) of an event as the cause of the deterioration state of a *conservation object* is based on some *assessor*'s (*E39_Assessor*) *belief* (*I2_Cause_Belief*). The belief has a particular type (*I4_Cause_Type*) and certainty *value* (*I6_Cause_Certainty_(Belief)_Value*).

Image 10: Concept map of deterioration process/effect with classes and object properties from EAMENA.

3.2. Discussion

Taking into account each model's approach regarding the representation of a deterioration process/effect, we created a concept map that covers this field of interest using classes and object properties from CIDOC CRM, CRMsci and CRMinf.

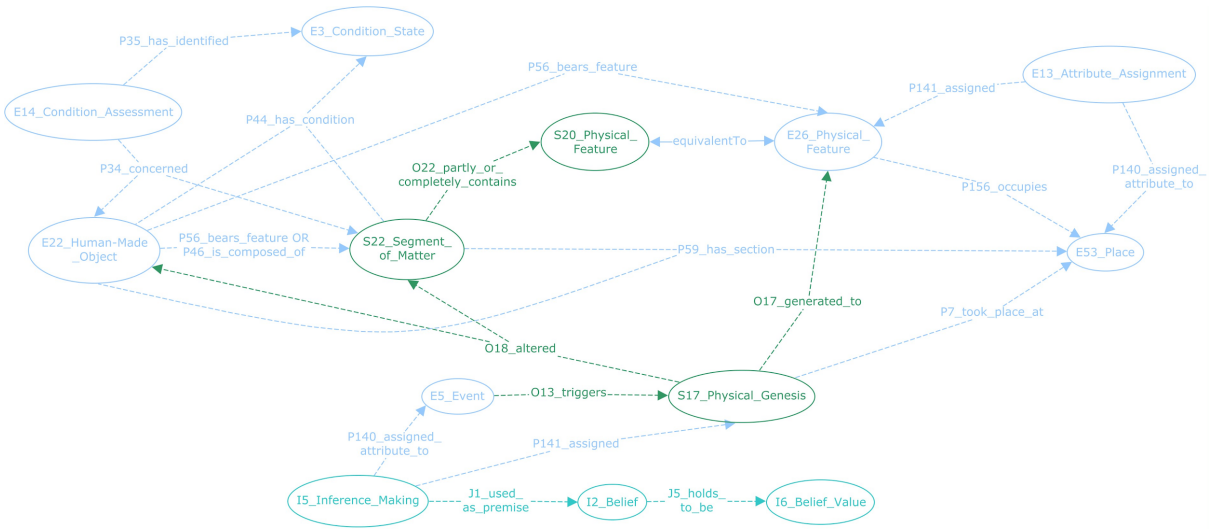

Image 11: Concept map of deterioration process/effect with classes and object properties from CIDOC CRM, CRMsci and CRMinf.

The concept of *deterioration* can be perceived both as a process and as an effect of a process (identifiable feature on a conservation object). In terms of terminology, CnR experts may refer to both aspects of deterioration (process and effect) using the same term. The CRMsci class *S17_Physical_Genesis* may be useful for the representation of deterioration as a process.

The CRMcr and CPM models represent the deterioration effect introducing new classes as subclasses of the CIDOC CRM class *E55_Type*. On the other hand EAMENA follows almost the same practice, using the CRMsci class *S9_Property_Type,* which is a subclass of *E55_Type*. An alternative option (i.e. alternative using *E55_Type* and its subclasses) would be to use the CIDOC CRM class *E26_Physical_Feature* for the representation of deterioration effect. Furthermore, we understand that there is a need to link the deterioration process with the correspondent effect. Therefore we could use the CRMsci property *O17_generated_to* for that purpose or we need to introduce a new object property (e.g. *Xxx_has_effect*).

Additionally, it is important to be able to represent the cause of the deterioration process that eventually results in the observed deterioration effect. To this aim, CRMcr introduces the class *C14_Alteration_Factor* as a subclass of CIDOC CRM class *E55_Type,* while EAMENA uses the class *E5_Disturbance_Event* which is either i) a subclass of or ii) a class equivalent to CIDOC CRM class *E5_Event*. To our understanding, a deterioration process has a trigger (e.g. temperature rise, oxidative reaction) which can be related to some human or environmental factor. Therefore, we suggest the use of the CIDOC CRM class *E5_Event* for the representation of the cause of deterioration. We could further discuss how the human/environmental factors (e.g. temperature) can be represented.

There is also the need to represent the region of a conservation object where a deterioration effect is observed. CRMcr represents the region of a conservation object with the class *C15_Altered_Area*, which is a subclass of CIDOC CRM class *E55_Type*, and the CPM model with the class *EcpmA241_Surface_Area*. In EAMENA, the class *E55_Damage_Extent_(Type)*, which is a subclass of or a class equivalent to the CIDOC CRM class *E55_Type*, represents the extent of the region where the deterioration effect is

observed. We suggest that the region of the object where the deterioration effect is located can be represented with the CIDOC CRM class *E53_Place*. In Image 11 we present the use of *E53_Place* for the representation of both i) a specific region on a conservation object, and ii) a specific region on a structural layer of a conservation object. The structural layer of a conservation object (e.g. painting layer) can be represented with the CRMsci class *S22_Segment_of_Matter*.

Furthermore, all three models represent the concept of the *condition state* of a conservation object, by extending the CIDOC CRM class *E3_Condition_State*. However, it is not clear enough i) what exactly this class represents and ii) how it is linked with the deterioration process/effect. We suggest that the *E3_Condition_State* class would be useful for the representation of the overall state of a conservation object or a structural layer of an object presenting one or more deterioration effects.

Finally, EAMENA implements the reasoning about the cause-effect "story" of a deterioration process. EAMENA exploits classes and object properties from CRMinf in order to represent the assessment of an event as the cause of the deterioration state of a conservation object. We understand that such a representation might be useful, so for that purpose we included some classes and object properties from CRMinf in our concept maps (see Image 11) . However, we suppose that it is a matter that needs further investigation in order to specify in more detail the steps of the "cause-effect" inference process.

4. Risk & Risk Assessment

4.1. Modeling Approach

4.1.1. PARCOURS Project (CRMcr Model)

CRMcr does not introduce any class regarding risk and risk assessment.

4.1.2. Sapienza (CPM Model)

The CPM model represents the concept of *vulnerability assessment* with the CRMsci class *S5_Inference_Making*. To our understanding vulnerability assessment refers to the assessment of the vulnerability of a building, a group of buildings or an urban area in terms of deterioration. The assessment is based on a logic which is represented by the CRMinf class *I3_Inference_Logic*.

According to the CPM model, the *historical center of a city* (*Ecpm30_Historical_Center*) consists of different *components* (*Ecpm62_Urban_Aggregate, Ecpm3_Urban_Isolate_Building*, *Ecpm72_Cultural_Heritage, Ecpm73_Cultural_Heritage_Urban_Landscape_Element, Ecpm74_Urban_Spaces*). These components are subjected to a *vulnerability index* (*S5_Inference_Making*). The *vulnerability index* is deduced based on an *algorithm* (*I3_Inference_Logic*).

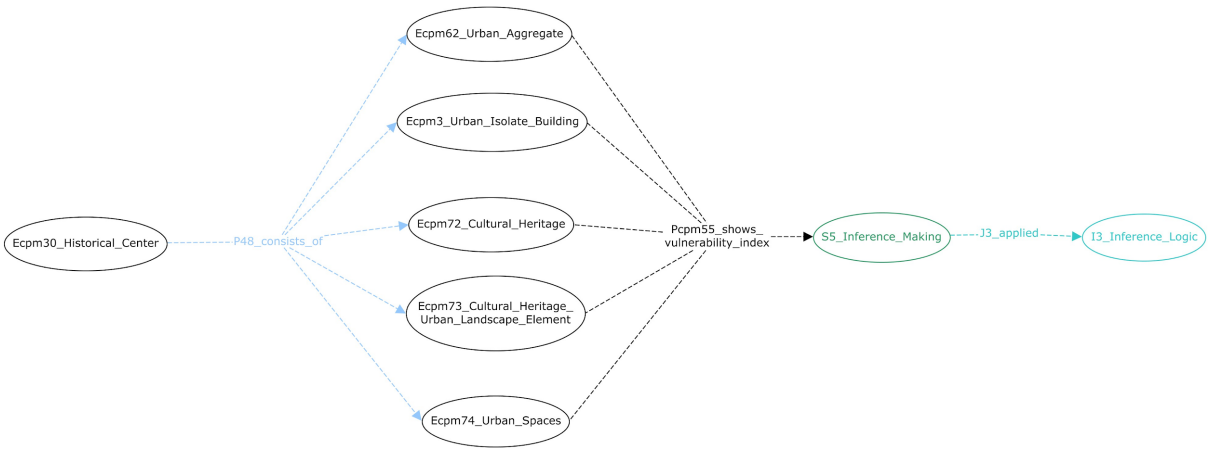

Image 12: Concept map of vulnerability and vulnerability assessment with classes and object properties from CPM.

4.1.3. EAMENA

The EAMENA model represents the concept of *risk* with the class *xx1_Potential_Risk_State* which is a subclass of the CIDOC CRM class *E2_Temporal_Entity*. Furthermore, EAMENA introduces the class *xx3_Possible_Event_Threat* as a subclass of the CIDOC CRM class *E5_Event*. The class *xx3_Possible_Event_Threat* is linked to the class *xx1_Potential_Risk_State* through the object property *YY3i_could_be*. Finally, it represents the concept of *risk assessment* with the class *xx2_Risk_Evaluation* which is a subclass of the CIDOC CRM class *E13_Attribute_Assignment*.

According to the EAMENA model, a condition assessment action (*E14_Condition_Assessment*) predicts the potential risk state (*xx1_Potential_Risk_State*) of a *conservation object*. The potential risk state has a certain type (*E55_Potential_Impact_Type*) and may be caused by an event (*E5_Threat_Event*) of a certain type (*E55_Threat_Type*). The event that potentially causes the risk state may trigger another event (*E5_Secondary_Threat_(Event)*) of certain type (*E55_Threat_Type*). The potential risk state is assessed by a risk assessment action (*XX2_Risk_Prediction_Evaluation*) which is carried out by some actor (*E39_Assessor*). The risk assessment action assigns a potential risk level (*I2_Risk_Level_Belief*), threat probability (*E55_Threat_Probability_Type*), extent of the risk (*E55_Risk_Extent*) and severity of the risk (*E55_Risk_Severity*). The potential risk level is based on some recommendation (*I4_Risk_Level_Proposition*) and presents some level of certainty (*I6_Risk_Level_Certainty*). The risk assessment observes a certain area (*S15_Assessed_Area_Vulnerability_and_Exposure*) which presents vulnerability of some type (*E55_Vulnerability_Type*) and has some note (*E62_Exposure_(Note)*).

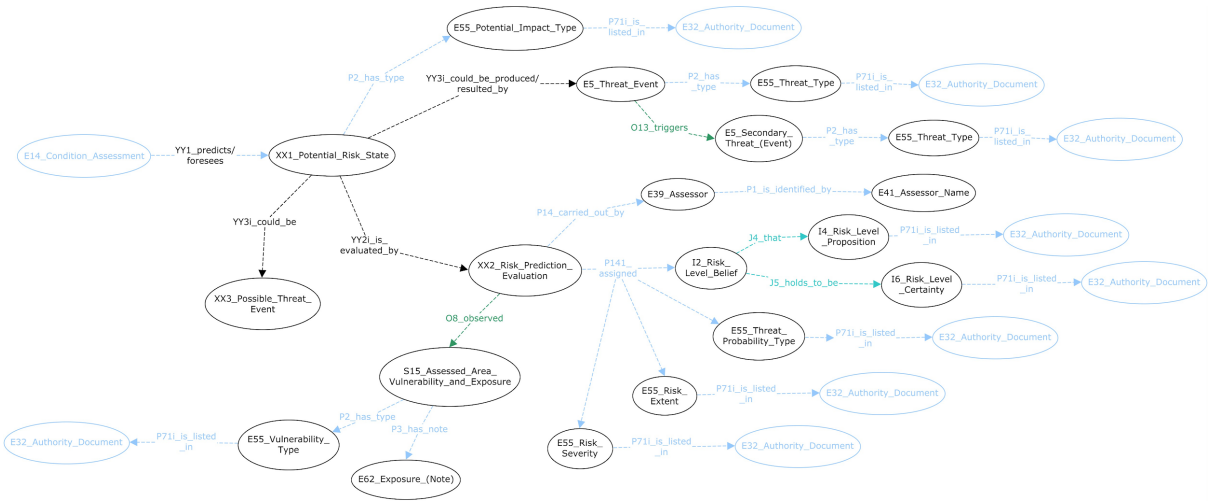

Image 13: Concept map of risk and risk assessment with classes and object properties from EAMENA.

4.2. Discussion

Taking into account each model's approach regarding the representation of risk and risk assessment, we created a concept map that covers this field of interest using classes and object properties from CIDOC CRM and CRMsci.

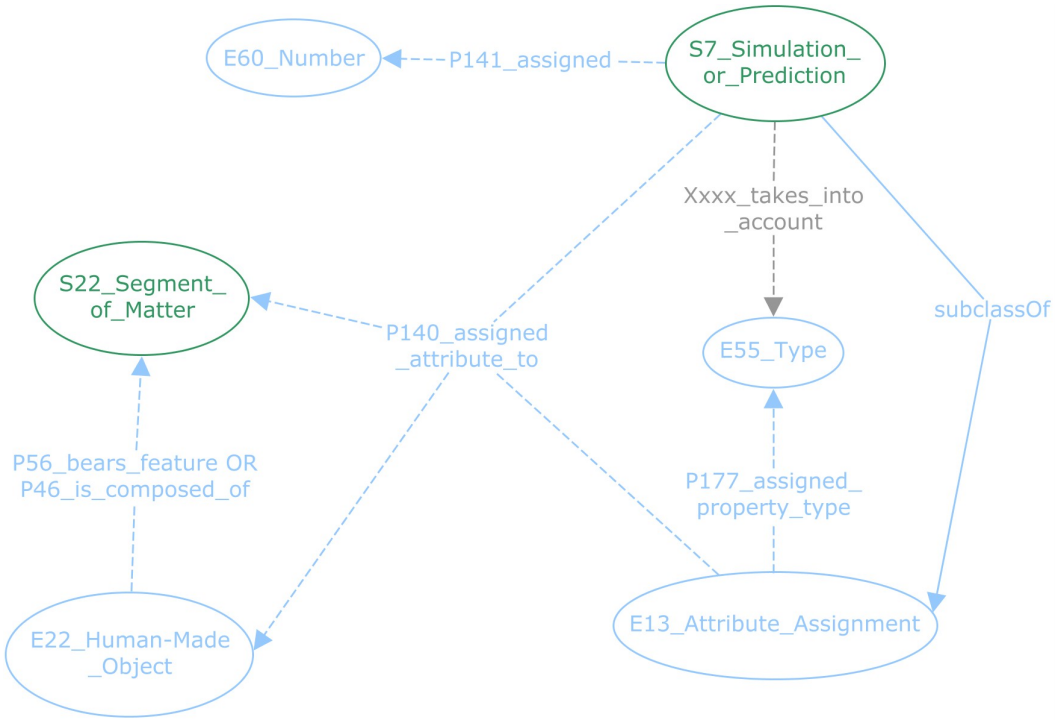

Image 14: Concept map of risk and risk assessment with classes and object properties from CIDOC CRM and CRMsci.

EAMENA represents the risk assessment concept with the class *XX2_Risk_Prediction_Evaluation* which is a subclass of i) the CIDOC CRM class *E13_Attribute_Assignment* and ii) the CRMsci class *S4_Observation*. On the other hand, the CPM model perceives risk assessment as the calculation of risk using the equation: Risk =

Dangerousness * Vulnerability * Exposure, which in turn is represented by the CRMinf classes *I5_Inference_Making* and *I3_Inference_Logic*.

We understand the need of a class that represents the activity of risk assessment, though we suggest further examination of already existing classes, such as the CIDOC CRM class *E13_Attribute_Assignment* or the CRMsci class *S7_Simulation_or_Prediction* or the CRMinf class *I5_Inference_Making*, in order to understand whether they could represent risk assessment activity.

In the concept map above (Image 14), we use the CRMsci class *S7_Simulation_or_Prediction* for the representation of risk assessment and the CIDOC CRM class *E13_Attribute_Assignment* for the representation of vulnerability assessment. According to the CPM model, vulnerability assessment is required for the final risk assessment of a certain risk for a certain conservation object.

Finally, we understand the need to represent the potential deterioration process or effect that threatens the conservation object, or in other words to represent *"what the risk refers to"*. However, we are not certain which CIDOC CRM class could be used in this case. It is important to emphasise that we are still in the process of understanding the nature of risk in conservation. It is likely that risk can only manifest a potential future state of the object and therefore a new class based on *S17_Physical_Genesis* but in a future time may be necessary. In the concept map above (Image 14) we use the CIDOC CRM class *E55_Type* for the representation of a potential deterioration (effect or process), while we suggest the extra object property *Xxx_takes_into_account* in order to represent the correlation between the risk assessment and the parameters that the assessment takes into account (e.g. vulnerability).

5. Measurement

5.1. Modeling Approach

5.1.1. PARCOURS Project (CRMcr Model)

The CRMcr model introduces the class *C16_Scientific_Study* as a subclass of the CIDOC CRM class *E7_Activity*. *C16_Scientific_Study* has two subclasses: i) the CIDOC CRM class *E16_Measurement* and ii) the CRMsci class *S4_Observation.* The classes *E16_Measurement* and *S4_Observation* both have as subclass the CRMsci class *S21_Measurement*. The class *S21_Measurement* has as subclass the CRMsci class *S3_Measurement_by_Sampling*, as well as the CRMcr classes *C19_Scientific_Imagery* (and its subclasses *C18_Photography, C35_Radiography, C57_Microscopy*), *C55_Spectrometry* and *C56_Chromatography,* which represent specific measurement and analysis methods. Additionally, CRMcr introduces the class *C55_Experimental_Condition*, which is a subclass of the CIDOC CRM class *E3_Condition_State*. *C55_Experimental_Condition* appears to represent the conditions under which a measurement is conducted. Furthermore, CRMcr introduces the class *C50_URL*, as a subclass of the CIDOC CRM class *E73_Information_Object*, as well as the classes *C59_Section, C58_Spectrum* and *C64_Curve*, as subclasses of the CIDOC CRM class *E36_Visual_Item*. The aforementioned CRMcr classes represent specific types of information regarding results of measurements.

Finally, CRMcr introduces the class *C13_Analysis_Technique* (and its subclasses *C20_Scientific_Imagery_Technique*, *C61_Spectrometry_Technique*, *C60_Chromatography_Technique, C17_Sample_Taking_Technique*), as a subclass of CRMcr class *C11_Technique* and represents the different measurement techniques. *C11_Technique* is a subclass of the CIDOC CRM classes *E29_Design_or_Procedure* and *E55_Type*.

According to the CRMcr model, a measurement process (*S21_Measurement*) is applied on a conservation object, which is under observation (*S15_Observable_Entity* and its subclasses). The measurement activity is applied specifically on a specific area (*C62_Area*) of the object. The measurement process follows a procedure (*C10_Procedure*) that uses some technique(s) *(C13_Analysis_Technique*), instrument(s) (*C12_Instrument*) and material(s) (*S10_Material_Substantial*). Additionally, the measurement activity measures a specific property (*S9_Property_Type*) of the conservation object or its sample, under specific conditions (*C55_Experimental_Condition*). Also, measurement may continue some other activity (e.g. *S2_Sample_Taking* of *S13_Sample*). Eventually, the measurement activity has some results (*E62_String*) and produces some visual or other information (*E73_Information_Object*).

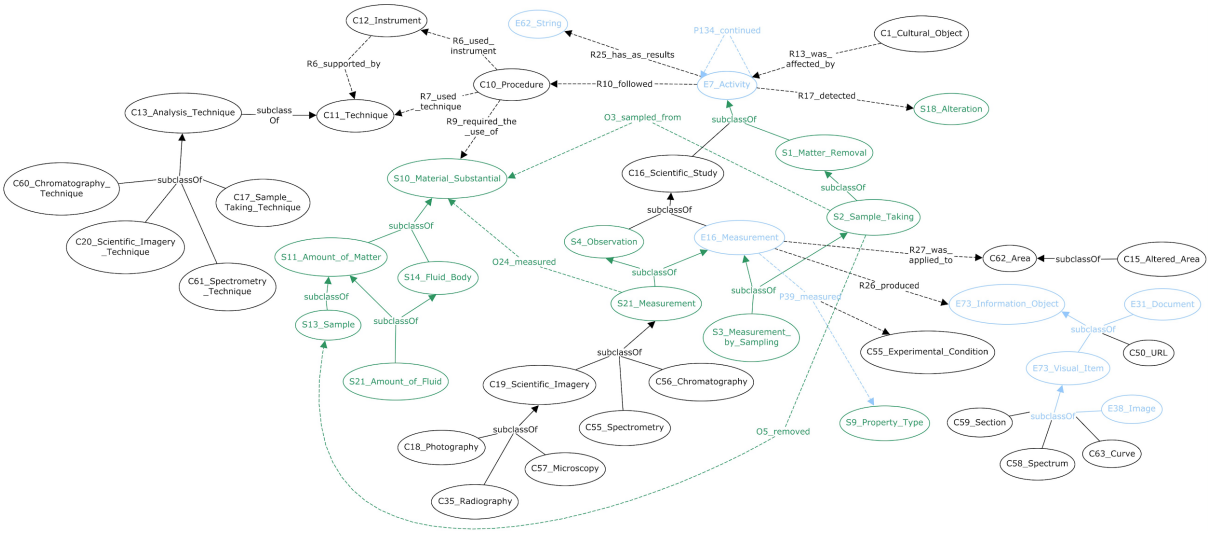

Image 15: Concept map of a *measurement* with classes and object properties from CRMcr.

5.1.2. Sapienza (CPM Model)

The CPM model introduces the class *EcpmP02_Heritage_Process_Investigation*, as a subclass of the CPM class *EcpmP3_Heritage_Process_Activity* and represents the processes of scientific investigation. We assume that scientific investigation is a superclass -in terms of meaning- that includes -among other activities (e.g. *EpcmP05_Bibliographical_Investigation_Activity*)- measurement activities. *EcpmP3_Heritage_Process_Activity* is a subclass of the CIDOC CRM class *E5_Event*. In one of the published works about the model (that we studied) a more detailed taxonomy is presented with *EcpmP3_Heritage_Process_Activity* as superclass. In this case, there are two classes that refer to the concept of investigation: the class *EpcmP03_Heritage_Indirect_Investigation* and the class *EpcmP09_Heritage_Direct_Investigation_Activity*. Both of the classes have subclasses that represent specific types of investigation processes (e.g.

EpcmP17_Constructive_Techniques_Analysis_Activity). Additionally, the CPM model introduces *EcpmP32_Heritage_Process_Resource* which represents the means of an investigation process (e.g. tools, methods, samples).

According to the CPM model, an investigation activity (*EcpmP02_Heritage_Process_Investigation*) has some input (*E73_Information_Object*), it is carried out by an actor (*E39_Actor*) and it is applied on a conservation object (*E24_Physical_Man-Made_Thing*). Investigation activity uses some resources (*EcpmP32_Heritage_Process_Resource*), provides some results (*E73_Information_Object*) and contributes with those results to the assignment of some attribute (*E13_Attribute_Assignment*) to the conservation object.

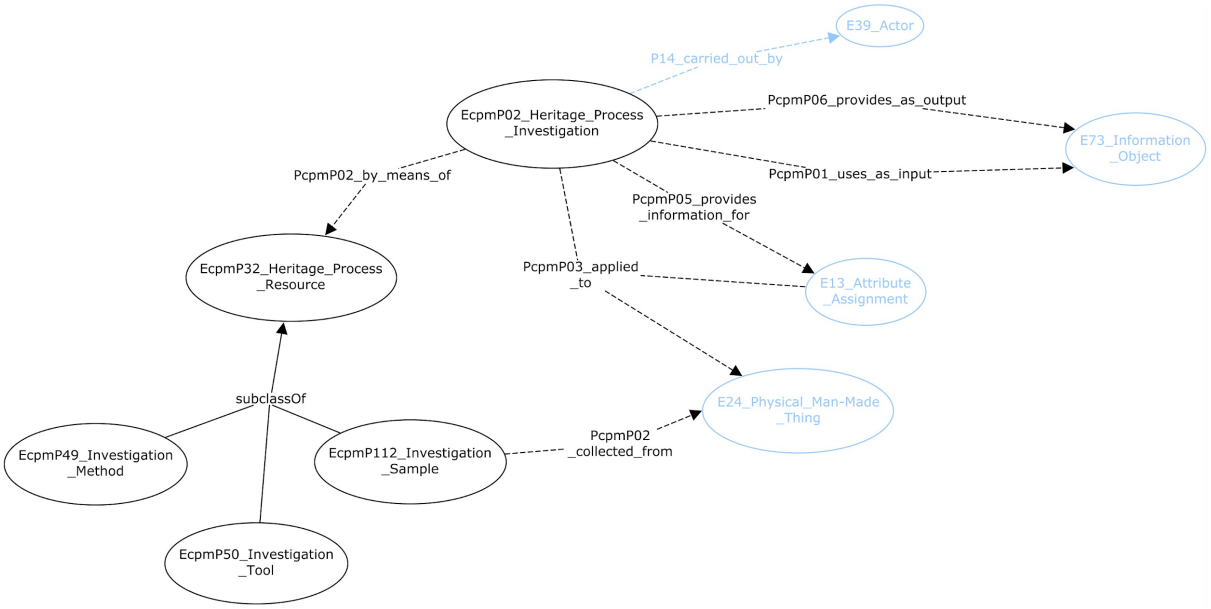

Image 16: Concept map of a *measurement* with classes and object properties from CPM.

5.1.3. EAMENA

EAMENA represents *measurement activity* with the CIDOC CRM *E16_Measurement*. It also represents *investigation activity* with the class *E7_Investigation/Activity* - which is not clear if it is a subclass of or equivalent to the CIDOC CRM class *E7_Activity*.

According to the EAMENA model, a measurement (*E16_Measurement*) has a certain type (*E55_Measurement_Source_Type*) which is presented in some document (*E32_Authority_Document*). Furthermore, a measurement observes a certain dimension (*E54_Dimension*), which has a certain type (*E55_Dimension_Type*), value (E60_Number) and unit (*E58_Unit*). The type and the unit of the dimension are presented in some document (*E32_Authority_Document*). On the other hand, an investigation activity (*E7_Investigation/Activity*) is carried out by some actor (*E39_Investigator(Actor)*) in a particular time span (*E52_Activity_Time-Span*). An actor is identified by some appellation (*E41_Investigator(Actor)*) and has a certain role (*E55_Investigator_Role_Type*), which is presented in some document (*E32_Authority_Document*). Additionally, an investigation activity has a certain type (*E55_Activity_Type*) which is presented in some document (*E32_Authority_Document*). Measurement and investigation activities are conducted on physical things (*E24_Physical_Man-Made_Thing*) or sites (*E27_Site*).

Image 17: Concept map of a *measurement* with classes and object properties from EAMENA.

5.2. Discussion

Taking into account each model's approach regarding the representation of measurement, we created a concept map that covers this field of interest using classes and object properties from CIDOC CRM and CRMsci.

Image 18: Concept map of *measurement* with classes and object properties from CIDOC CRM and CRMsci.

First and foremost, CRMcr represents *measurement* with the CRMsci class *S21_Measurement*, while EAMENA represents the same concept with the CIDOC CRM class *E16_Measurement*. Additionally, CPM appears to represent the same concept with the class *EpcmP09_Heritage_Direct_Investigation_Activity*. EAMENA and CPM also introduce the concept of *investigation* using different classes (*E7_Investigation/Assessment_Activity* and *EcpmP02_Heritage_Process_Investigation* respectively), in comparison to the ones that they use for the concept of *measurement*. We could further examine the difference between the two concepts (investigation and measurement) and the respective class choices (e.g. is there any overlap and to what extent).

The subject of the measurement or the investigation activity (in other words what is measured) may be i) a conservation object (as a whole), ii) some feature of the conservation object, iii) a site. In cases that there is the need to represent i) some property of a surface or material of the conservation object, or ii) conditions of the environment of the conservation object, it is not clear what the conceptual path should include. We suggest the use of CRMsci *S9_Property_Type* for this purpose. However, we need to further discuss its use, especially in relation to the use of CIDOC CRM class *E54_Dimension*.

CRMcr represents the output of a measurement activity either with the CIDOC CRM class *E62_String* or *E73_Information_Object*. Generally the quantity of a property is represented by EAMENA and CRMcr with a conceptual path that includes the CIDOC CRM classes *E54_Dimension* and *E60_Number.* We agree that the use of that path is useful, though we could also discuss the use of the CIDOC CRM class *E89_Propositional_Object* for the representation of a measurement output (as *information*).

CRMcr introduces the class *C55_Experimental_Condition*, which (apparently) represents the conditions under which the measurement is conducted. We have not included this concept in the conceptual map, since it is not clear which CIDOC CRM or CRMsci class we could use in this case. We could further discuss the representation of the concept of *measurement conditions* to determine how it could be represented using CIDOC CRM.

Finally, we suggest that the full representation of the *measurement and investigation activities*, including the specific materials, techniques and equipment that have been used, is useful. Thus, we present a potential property path (see Image 18) using CIDOC CRM and CRMsci classes (*S11_Ammount_of_Matter, E29_Design_or_Procedure and E22_Human-Made_Object*) and object properties (*P16_used_specific_object, P33_used_specific_technique*).

6. Object technology

6.1. Modeling Approach

6.1.1. PARCOURS Project (CRMcr Model)

The CRMcr model introduces the class *C1_Cultural_Object* as a subclass of the CIDOC CRM class *E24_Physical_Man-Made_Thing*. *C1_Cultural_Object* has two subclasses i) the CRMcr class *C2_Immovable_Object* and ii) the CRMcr class *C3_Movable_Object. C1_Cultural_Object* and its subclasses represent the two main categories of tangible

Cultural Heritage. Additionally, CRMcr introduces the class *C5_Domain*, which is a subclass of the CIDOC CRM class *E55_Type*. *C5_Domain* (apparently) represents the type of a conservation object (e.g. painting). Furthermore, CRMcr introduces the class *C9_Shape* as a subclass of the CIDOC CRM class *E55_Type*. *C9_Shape* (apparently) represents the shape of an object, though its practical use is not clear - maybe an example would be useful. Furthermore, CRMcr introduces the class *C6_Manufacturing_Technique*, as a subclass of CRMcr class *C11_Technique*. *C11_Technique* is a subclass of both the CIDOC CRM class *E55_Type* and the CIDOC CRM class *E29_Design_or_Procedure*. *C6_Manufacturing_Technique* represents the conservation object's production technique.

According to the CRMcr model, a conservation object (*C1_Cultural_Object*) belongs to a collection (*E78_Collection*), has a certain shape (*C9_Shape*), falls within a certain domain (*C5_Domain*) and has witnessed a certain period of time (*E4_Period*). Additionally, the conservation object has specific dimensions (*E54_Dimension*), identifier (*C52_Inventory_Number, E42_Identifier*) and title (*E35_Title*). It is produced by a production process (*E12_Production*) which follows a specific production technique (*C6_Manufacturing_Technique*). The production was carried out by some person (*E39_Actor*).

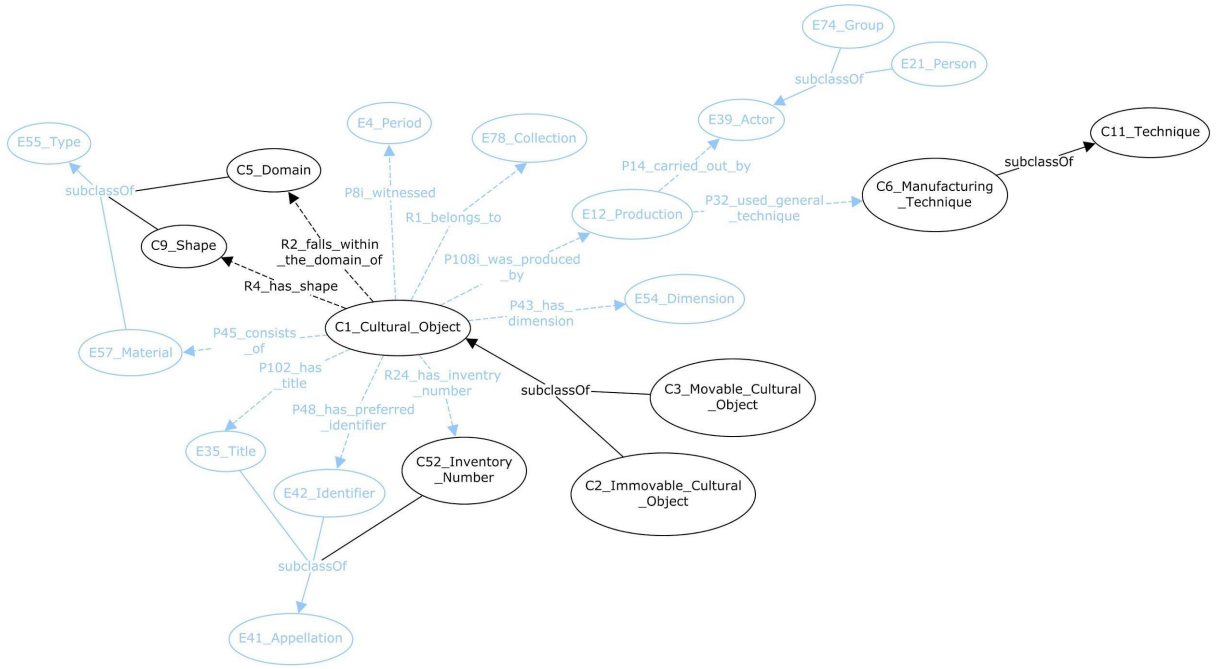

Image 19: Concept map of *object technology* with classes and object properties from CRMcr.

6.1.2. Sapienza (CPM Model)

The CPM model introduces the classes *CP1_Architectiral_Work, CP60_Urban_Unit* and *CP62_Urban_Unit_Aggregate* as subclasses of the CRMba class *B1_Built_Work*. *CP1_Architectiral_Work* has as subclasses the CPM classes *CP61_Urban_Unit_Single_Residential_or_Specialist_Building* and *CP63_Building_Unit*. The aforementioned CPM classes (apparently) represent different types of buildings.

Also, CPM model introduces the classes *CP30_Historical_Center, CP31_Spatial_Ensamble, CP32_Spatial_Unit, CP33_Spatial_Component* as subclasses of

the CIDOC CRM class *E92_Spacetime_Volume*. The aforementioned CPM classes (apparently) represent parts/components of buildings.

Additionally, the CPM model introduces the classes *CP2_Constructive_Unit, CP2_Constructive_Component and CP3_Constructive_Element* as subclasses of the CIDOC CRM class *E18_Physical_Thing.* The aforementioned CPM classes (*a*pparently) represent the different parts of a construction.

Also, CPM introduces the class *EcpmA237_Movable_Elements* as a subclass of the CIDOC CRM class *E24_Physical_Man-Made_Thing*. *EcpmA237_Movable_Elements* (apparently) represents objects or movable parts of a building (e.g. artwork shown in the building).

Furthermore, the CPM model introduces the classes *Ecpm71_Open_Air_Spaces* and *Ecpm73_Cultural_Heritage_Landscape_Elements* as subclasses of the CIDOC CRM class *E19_Physical_Object,* while it introduces the classes *Ecpm72_Cultural_Heritage* and *Ecpm74_Urban_Spaces* as subclasses of the CIDOC CRM class *E22_Man-Made_Object.* The aforementioned CPM classes (*a*pparently) represent the different types of spaces that belong to CH.

According to the CPM model, construction components (CPM subclasses of *E18_Physical_Thing*) are parts of the spatial units of a conservation object. A conservation object has been transformed (*E81_Transformation*) several times and the transformation resulted in the addition/removal/modification of components or the complete transformation into a different conservation object. Additionally, regarding the urban spaces, a historical center (*CP30_Historical_Center*) *is a subclass of E92_Spacetime_Volume* and consists of built elements (*E22_Man-Made_Object and B1_Built_Work*). Subclasses of *CP60_Urban_Unit* include *Urban Unit-Aggregates such as urban blocks with multiple houses (CP62_Urban_Unit-Aggregate) and Urban Unit-Isolated Building such as schools or hospitals which are considered a single building covering the equivalent area of a Unit-Aggregate (CP61_Urban_Unit_Single_Residential_or_Specialist_Building). CP62_Urban_Unit-Aggregate* consists of *CP63_Building Unit, such as individual houses. CP64_Building_Front* forms part of *CP62_Urban_Unit-Aggregate, CP61_Urban_Unit_Single_Residential_or_Specialist_Building, CP63_Building Unit* and *Ecpm71_Open_Air_Spaces. Ecpm71_Open_Air_Spaces can be Ecpm73_Cultural_Heritage_Urban_Landscape_Element and Ecpm74_Urban_Spaces.* These classes are still in development as discussions continue but the above is a basic representation of the decisions made so far.

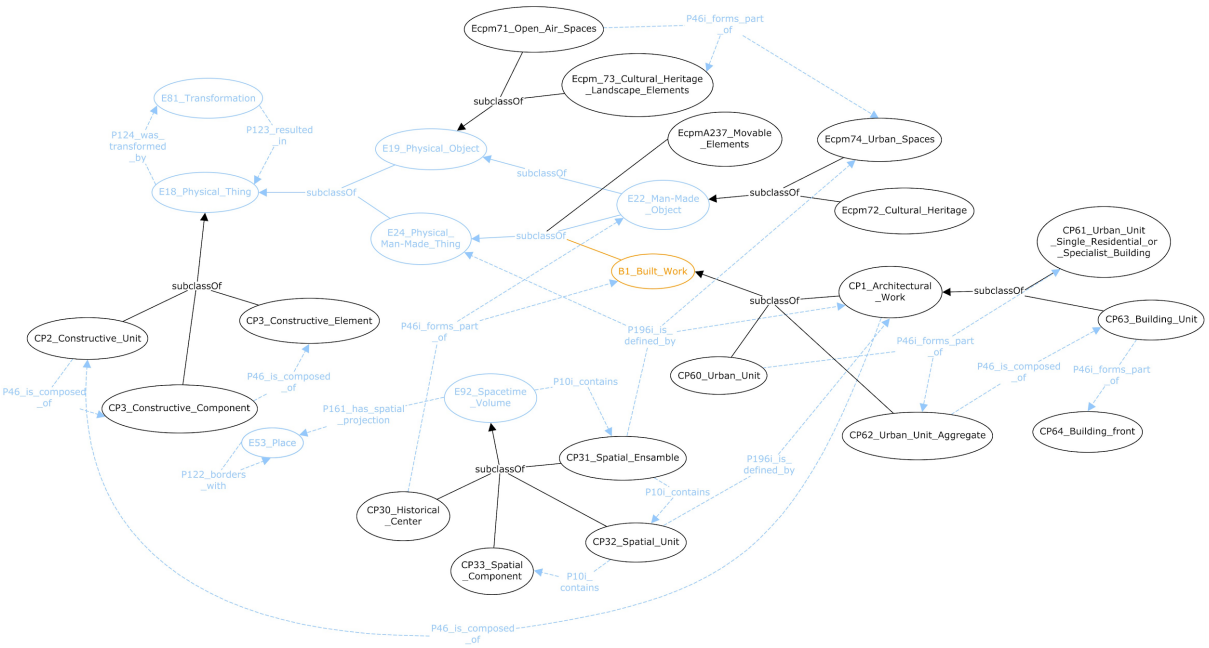

Image 20: Concept map of *object technology* with classes and object properties from CPM (in progress).

6.1.3. EAMENA

EAMENA represents the *production* of a conservation object with the CIDOC CRM class *E12_Production*. Furthermore, it represents the inference behind dating and interpretation of the production using the class *I5_Date_and_Interpetation_Inference_Making* - and it is not clear if it is a subclass of or equivalent to the CRMinf class *I5_Inference_Making*. It also represents the *assignment* of a specific feature type to a conservation object using the class *E17_Heritage_Feature_Classification_Assignment* - and again it is not clear if it is a subclass of or equivalent to the CIDOC CRM class *E17_Type_Assignment*.

According to the EAMENA model, a conservation object (*E24_Physical_Man-Made_Thing*) has been produced through a production activity (*E12_Production*). The *assignment of dating and interpretation* of a production activity of a *conservation object* (*I5_Date_and_Interpetation_Inference_Making*) is based on some *person*'s (*E39_Actor*) *beliefs* (*I2_Cultural_Period_Belief, I2_Function_Belief, I2_Interpretation_Belief*). The belief has i) types (*I4_Cultural_Period_Broader_Type_(Proposition), I4_Function_Type_(Proposition_Set), I4_Interpretation_Type_(Proposition_Set)*), which may be narrower (*I4_Cultural_Period_Narrower_Type*) and ii) certainty *value* (*I6_Period_Certainty_(Belief)_Value, I6_Function_Certainty_(Belief)_Value, I6_Interpetation_Certainty_(Belief)_Value*). Types and certainty values are presented in some *document* (*E32_Authority_Document*). Additionally, the *assignment of dating and interpretation* of a production activity of a *conservation object* has some time-span (*E32_Authority_Document*). Furthermore, the classification of the conservation object (*E17_Heritage_Feature_Classification_Assignment*) assigns a certain type (based on its technology and use) (*E55_Heritage_Feature_Classification, E55_Feature_Current_Use*) to the conservation object which is presented in some *document* (*E32_Authority_Document*).

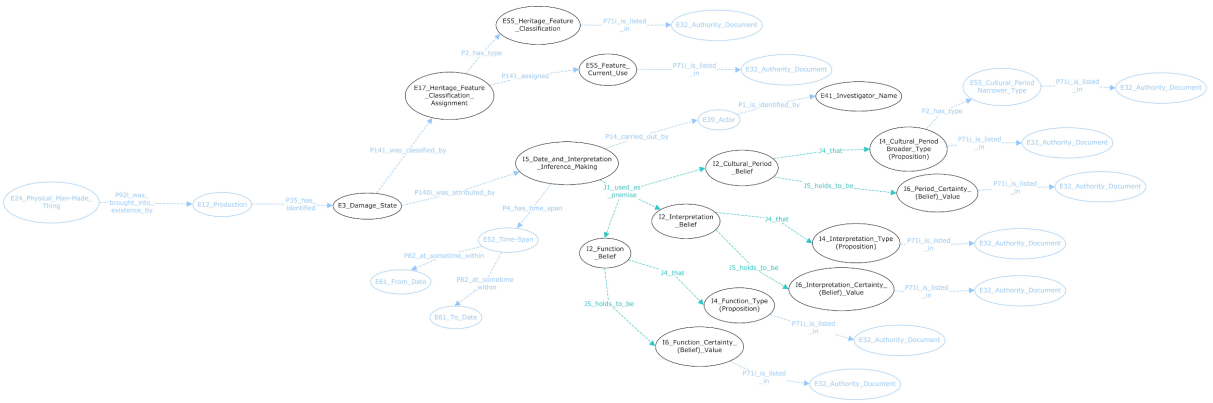

Image 21: Concept map of *object technology* with classes and object properties from EAMENA.

6.2. Discussion

Taking into account each model's approach regarding the representation of object technology, we created a concept map that covers this field of interest using classes and object properties from CIDOC CRM and CRMinf.

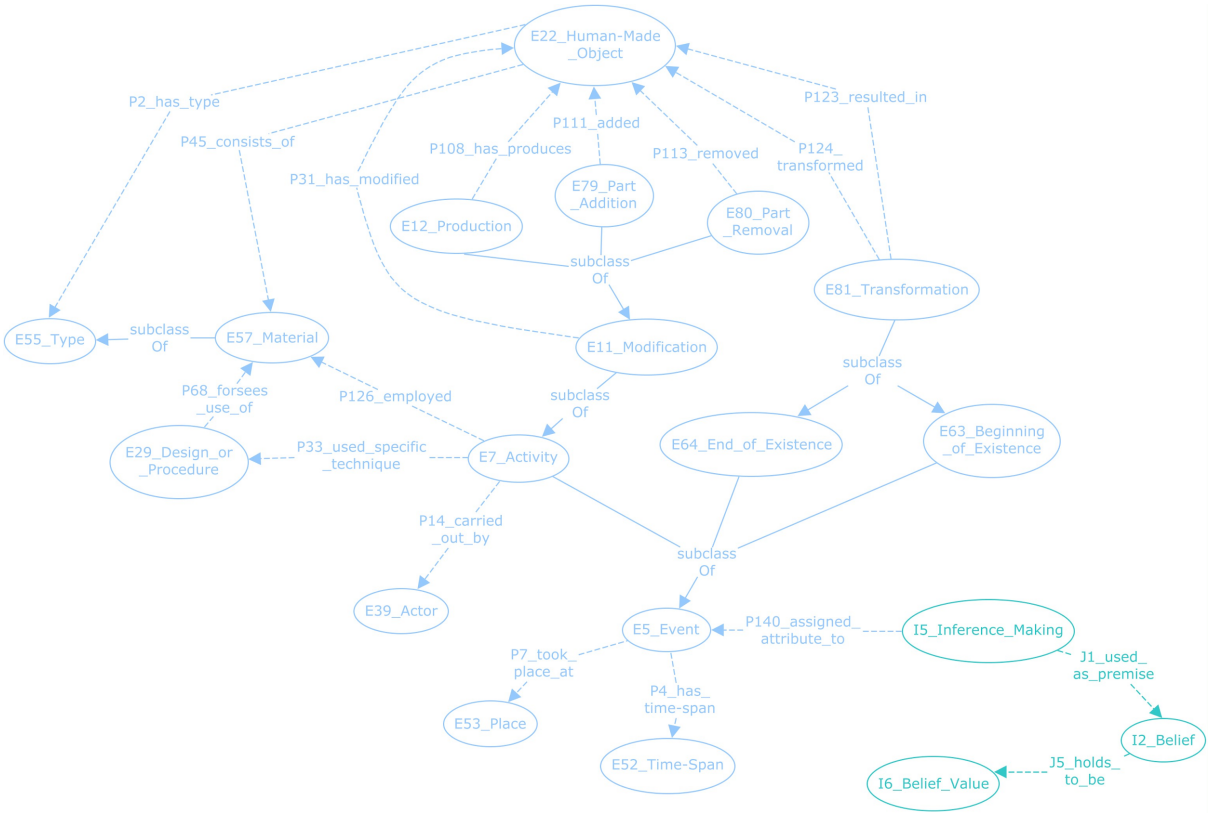

Image 22: Concept map of *object technology* with classes and object properties from CIDOC CRM and CRMinf.

First and foremost, CRMcr and CPM introduce classes for the representation of types of conservation objects. We understand that those classes may be useful for a specific application but we are not sure to which extent they are necessary as extensions of CIDOC CRM.

The production of a conservation object, as well as its modification or even transformation though time can be well represented using CIDOC CRM classes and properties as the reviewed models indicate. Therefore, we also adopted the CIDOC CRM paths for the representation of *production* and *modification* of a conservation object.

EAMENA implements the reasoning about the production and dating history of a conservation object. We understand that such a representation might be useful, so for that purpose we included certain classes and object properties from CRMinf in our concept maps (see Image 22).

Finally, CRMcr introduces the class *C9_Shape*. We have not included it in our concept map, though we suggest further discussing whether the categorical nature of shape (a sub-class of *E55_Type*) would be useful in conservation.

7. Overall conclusions & future work

The analysis of the three models according to the six axes of CnR knowledge (see Introduction), as well as the discussion over their representation using concepts and relations from CIDOC CRM and its compatible models (CRMsci, CRMinf, CRMsoc) (see Discussion sections) led to some interesting conclusions and pointers for future work:

1) We recognise that CIDOC CRM and its compatible models cover a significant part of CnR knowledge. However, due to the broader nature of CIDOC CRM and its compatible models, concepts and relations may appear too general for the CnR domain. In several cases it is not obvious which is the more appropriate class, object property or even the most appropriate property path in order to represent CnR data. Analyzing and experimenting with CIDOC CRM and its compatible models, generated a number of ideas for representing the different conceptualisation aspects of CnR (e.g. how to represent alteration phenomena), that can trigger further research and experimentation, eventually leading to specific implementation recommendations. As such, we propose the development of a CRM profile for the representation of: object technology, conservation activity, conservation plan, deterioration process and effect, risk assessment and analysis and measurement. In our opinion this work must be conducted by CnR specialists in collaboration and under the guidance of the CIDOC CRM community.

2) In some cases we recognised the need for the introduction of extra classes and properties that extend CIDOC CRM and its compatible models, in order to represent concepts of the CnR domain more precisely. The suggestions for CIDOC CRM extension are:

- Judging from its scope note, the *E11_Modification* class seems to encompass two quite distinct entities: i) production of an object (from raw materials) and ii) conservation of an object, which is further divided in the description into *preventive* and *restorative* treatment. We are also aware of a new version of the scope note (based on Issue 506) which clarifies that *E11_Modification* represents conservation treatments (effective or not). However, even in the new scope note i) production of an object is still included and ii) preservation actions are excluded. As such, we suggest:

    - the use of *E11_Modification* for the representation of remedial conservation and restoration actions. Furthermore, we suggest the introduction of the class *Xxx_Remedial_Conservation_&_Restoration_Intervention*, as a subclass of the CIDOC-CRM class *E11_Modification* (in order to separate *production* and *conservation* concepts).

    - the use of *E7_Activity* for the representation of preventive conservation actions. Furthermore, we suggest the introduction of the class *Xxx_Preventive_Conservation_Intervention*, as a subclass of the CIDOC-CRM class *E7_Activity.*

    - the introduction of properties i) *Xxx_was_motivated_by_alteration|deterioration* (with domain the CIDOC CRM class *E7_Activity*, and range the CRMsci class *S18_Alteration|S17_Physical_Genesis*), and ii) *Xxx_was_motivated_by_effect* (with domain the CIDOC CRM class *E7_Activity* and range the CIDOC CRM class *E26_Physical_Feature*), as sub-properties of the CIDOC CRM property *P17_was_motivated_by.*

- We suggest the introduction of the class *Xxx_Equipment*, as a subclass of the CIDOC-CRM class *E55_Type*, as well as the introduction of the property *Xxx_foresees_use_of_equipment* as a sub-property *P67_referes_to* (with domain the CIDOC CRM class *E29_Design_or_Procedure*, and range the class *Xxx_Equipment*). It will work in analogy with *E29_Design_or_Procedure → P68_foresees_use_of → E57_Material*.

- Conservation documentation uses ordinal scales for the documentation of the condition and observed features of the conservation object or the risk level of occurrence of harmful events. For example, as the EAMENA model suggests, a CnR expert may determine that the condition of a painting is *excellent* or that the level of risk is *high*. We could discuss an appropriate “path” based on which such values can be represented using CIDOC CRM. In this context, we could discuss the introduction of an extra class (*Xxx_Ordinal_Value* class) as a subclass of CIDOC CRM class *E55_Type*. Additionally, we could introduce either the object property *Xxx_is_conceptually_greater_than* (is conceptually less than) (with domain and range the CIDOC CRM class *E55_Type*) as proposed in Issue 407 to represent the order of the ordinal values in a certain scale. Finally, the class *Xxx_Ordinal_Value* must be connected with a numerical value, since we often need to quantify ordinal values; for example, in the context of a decision table the ordinal values of the scale *excellent to bad* will correspond to numbers from 5 to 1.

3) The conceptual aspects of risk assessment need further research in terms of modelling. The approaches of the CPM and EAMENA models are interesting, though dissimilar. The work of the two research teams indicates that specialists of CnR domain may perceive the concepts of risk and risk assessment in a different way and they represent them in a different context. More work is required for the understanding of the different meanings of risk assessment, the nature of the data to be represented and the level of coverage by existing classes and object properties of CIDOC CRM and its compatible models.

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