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Modelling The Art Market in The Semantic Web. A Preliminary Analysis

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Abstract

The paper presents the current stage of an ongoing project at the Fondazione Federico Zeri, aimed at the modelling of the art market starting from the recognition of the peculiarities of this sector and relying on the data collected by this institute during its research activities on its documentary collection. Specifically, this essay provides a preliminary analysis of the domain, aimed at guiding in the development of an ontology able to describe agents, events and sources which define the art market and enable its investigation. The recognition of existing conceptual models is hence followed by a reconstruction of the studied domain thanks to motivating scenario, examples and competency questions collected during the first iteration of the SAMOD methodology. For each scenario, the paper will provide the most relevant entities and will draft an alignment with existing ontologies, as well as propose necessary integrations.

Keywords: Ontology engineering, Digital Art History, Art Market, Knowledge Representation, Semantic Web, Dossier Digital Art History

Il seguente articolo presenta lo stadio attuale di un progetto in corso presso la Fondazione Federico Zeri volto alla modellizzazione del mercato dell'arte a partire dal riconoscimento delle specificità che caratterizzano questo settore e dai dati raccolti dall'istituto di ricerca bolognese nel corso del trattamento delle proprie collezioni documentarie. In particolare, il saggio fornisce un'analisi preliminare del dominio volta a guidare la definizione di un'ontologia che sia in grado di descrivere i principali agenti, eventi e fonti che lo definiscono e che ne permettono l'indagine. Dopo aver fornito i riferimenti ad altre ontologie e modelli presi in esame nel corso del progetto, l'articolo indaga in profondità il mondo del mercato utilizzando la metodologia SAMOD: per ognuno dei tre moduli in cui è stata suddivisa l'ontologia vengono quindi proposti scenari, esempi e domande di competenza, elencate le entità più rilevanti e proposti sia un allineamento con le ontologie esistenti, sia alcune necessarie integrazioni.

Keyword: ontologie, digital art history, mercato dell'arte, rappresentazione della conoscenza, web semantico

Introduction

Among the many fields of research related to art history, art market studies is one that has seen a major increase in recent years.

After focusing on the study of artists' personalities, contributing to the reconstruction of their catalogues, and defining a shared art historical canon, scholars have recently returned the history of works as material objects to the center of their interest. The movements of paintings, sculptures, and other artistic items; their confluence in different collections that reflect specific tastes; the dispersal and recomposition of cultural heritages in areas different from those in which they were produced; the commercial strategies of the agents who facilitated this network of trade: all these have become increasingly investigated topics. Many initiatives and interdisciplinary projects about the art market and history of collecting were promoted by research centers and a rich literature was produced, including specialized journals and entire book series. Among them, at least the Zentralarchiv für deutsche und internationale Kunstmarktforschung (ZADIK); the Forum Kunst und Markt, with its *Journal for Art Market Studies*; the *Project for the Study of collecting and Provenance* of the Getty Research institute; the *Antique dealers project* of the University of Leeds, are worth mentioning (for an overview, [3]). Moreover, the Bloomsbury Art Markets database, including numerous entries about protagonists of the international art market since 1900, has been recently launched with the aim of becoming a reference point for scholars in the field (Bloomsbury n.d.).

The Fondazione Federico Zeri has actively participated in this debate, with a focus on the art market in Italy in the 19th and 20th centuries. In addition to promoting conferences and publications ([1]), it has recently supported two research grants aimed at collecting unpublished information on dealers and collectors linked to the archive and the personal history of its founder.

As is well known, the Fondazione preserves the documentary collections of Federico Zeri (1921-1998), who was one of the leading art historians of the last century and an infallible *connoisseur*. They comprise a photo archive composed by 290,000 photographs of artworks and monuments, a library made of 46,000 books, and a collection of 37,000 auction catalogues, the largest of its kind in Italy. The scholar has used these resources as indispensable working tools to carry out his work as an independent scholar. In his career, he has been an adviser to dozens of art galleries, antiquaries, collectors, and auction houses, guiding them in their respective purchases and sales on the market. This activity is reflected in the handwritten annotations on the photographs and volumes. Among them, more than 500 names of individuals active in the market during the last two centuries were retrieved. How to systematize, normalize, and deepen data about these subjects was one of the main aspects of the cataloging project of the documentary collections ([17]).

Despite the studies and resources cited above, we realized how difficult it was to retrieve complete and detailed information about these figures using traditional art historical research methodologies. The nature of the art market entails a number of resistances to the dissemination of data on buyers, dealers, and sale prices of works. The lack of reliable data about transactions has proven to be the first in a series of aspects that characterize this domain and distinguish it from other business sectors.

First, those of antique dealers are often family-run businesses in which grandparents, children and grandchildren frequently use the same names: this results in extreme difficulty in figuring out to which different individuals certain information refers. On the other hand, the corporate name of a given gallery may change several times over time, for example, as a result of the

opening of new branches or the establishment of more or less stable joint ventures with other partners. Alongside the figure of the dealer revolves a wide network of advisers and collaborators. These include restorers, informants, and scholars with expertise in certain areas of art historical production, or in specific periods and styles, whom antiquarians or auction houses use to determine the quality and value of particular pieces. They may assist in writing files and catalogues, organizing sales, promoting dealers to collectors or museum directors. Being able to reconstruct and represent this network can contribute significantly to understanding the contexts and mechanisms of the art market.

Another typical aspect concerns what appears to be the very core of the domain: the transaction. The price of the works offered for sale depends not on their intrinsic characteristics but on a number of external elements that concur to determining their commercial value: first of all, on the attributions made by more or less authoritative art historians that accompany the pieces; then on their collecting history and state of preservation; again, on the fortune that a given style or artist comes to have at a given historical moment, in parallel with the evolution of fashion and taste, and so on.

Given the difficulty of accessing the antiquarians' personal archives, the study of the art market involves the use of other, sometimes non-canonical sources: trade guides, narrative and autobiographical texts, commercial magazines of the time, but, above all, the photographs of the works put up for sale initially addressed to advisors and potential clients, which have since been deposited in the photographic collections of scholars or art-historical institutions ([3]). It is no coincidence that it was from the cataloguing projects of these archives that the need emerged to investigate and systematize information on the subject.

The last type of source to be considered are the direct testimonies of market agents and their successors (children, grandchildren, colleagues etc.). The research promoted by the Fondazione involves extensive use of direct interviews and oral testimonies given by these individuals, which researchers are collecting and transcribing.

The ontology presented here in its guidelines, and currently under construction, aims to represent these and other specific aspects of the art market domain, and aspires to become a reference model for anyone interested in structuring, enhancing, and integrating scholarly data related to this field.

State of the art

The construction of an ontology for the art market domain requires at first a recognition of this multifaceted research field, in order to identify a selection of relevant projects concerning the description of objects, agents, and transactions typical of this domain.

As the project mainly deals with cultural heritage data, the principal reference ontology is CIDOC-CRM, the conceptual model proposed by ICOM which is a standard for the semantic description of pieces of information in this domain. One of the main peculiarities of this project is the relevance of the notion of *event*. Indeed, this approach permits "a more accurate view of the past or current life history of a cultural object, […] interprets more effectively history and especially heterogeneous and complex information resources that […] need to be linked and interpreted in order to capture knowledge" ([9]: 1).

In addition, this class also permits to model one of the core elements of the art market, which is the economic transaction. The solution proposed by CIDOC-CRM puts forward a streamlined

definition of this phenomenon, which is mainly corresponding to a change either in the possession or in the custody of a crm:E18_Physical_Thing instance. Since this model already defines all the main pieces of information usually used by researchers in the art historical domain, further economic factors described by other ontologies and conceptual models (e.g. see [15]) will be thus not considered.

In this perspective, our final ontology will be centered on this class as well, which will enable us to link different modules conceived for the description objects, documents, agents. While the first two can still be defined by CIDOC-CRM (specifically through the class crm:E18), the internal dynamics within art galleries are difficult to describe with the ICOM standard model. Consequently, an integration with another module, focused on the structure of organizations, has been deemed necessary.

Reynolds ([22]) already proposed *The Organization Ontology* (Org), which is an effective tool to describe the roles and position within a company, the changes in its major characteristics, as well as modification in the personnel. Moreover, this model shares relevant features with CIDOC-CRM class hierarchy. In particular, the class org:ChangeEvent, through which modifications of the studied company can be asserted, can be interpreted as a better specification of crm:E5_Event. Besides, Org integrates a widely used pattern in modelling the agent, which is actually an imported class from FOAF (http://xmlns.com/foaf/0.1/) and which can be aligned with crm:E39_Actor. Org main class, org:Organization, is defined as a subclass of foaf:Agent, on the same hierarchical level as the other two subclasses foaf:Person and foaf:Group.

The enhancement of CIDOC-CRM model for the description of sources and evidences has been instead already suggested by the project *Zeri&LODE*, which serialized in linked open data the metadata of the photographs of the Zeri Photo Archive related to the artworks of the Italian Cinquecento. Indeed, this initiative translated into two complete ontologies the *Scheda F* (F Entry, for photographs) and *Scheda OA* (OA Entry, for artworks) defined by Italian ICCD (Central Institute for Cataloging and Documentation of the Ministry of Culture), thanks to which it is also possible to express main bibliography connected to the catalogued item. CiTO (Peroni and Shotton 2012) was hence reused to quote sources to reconstruct the attribution of an artwork, while HiCO ([8]) was imported "to describe the interpretation process relative to subjective attributions" ([7]: 4).

As the final ontology will be asked to re-use some of these existing modules, this brief overview serves as premise for the analysis of more specific projects, assessing both the degree of interoperability with community standards and the ability of modelling relevant information for art historical research. For instance, an interesting endeavor in modelling the art market has been done by Filipiak et al. ([11]), which emphasizes mainly the economic characteristics of an auction in the art market. The quoted conference paper displays two main excerpts of the ontology, reported in Figura 1and Figura 2.

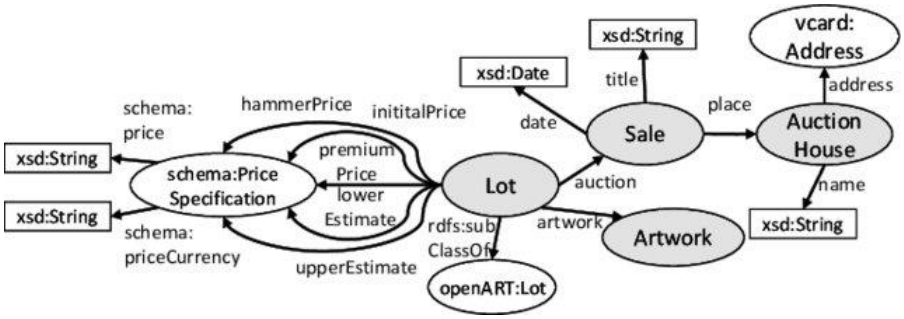

Figura 1. Excerpt of the art auction ontology, sales data (from Filipiak et al. 2016)

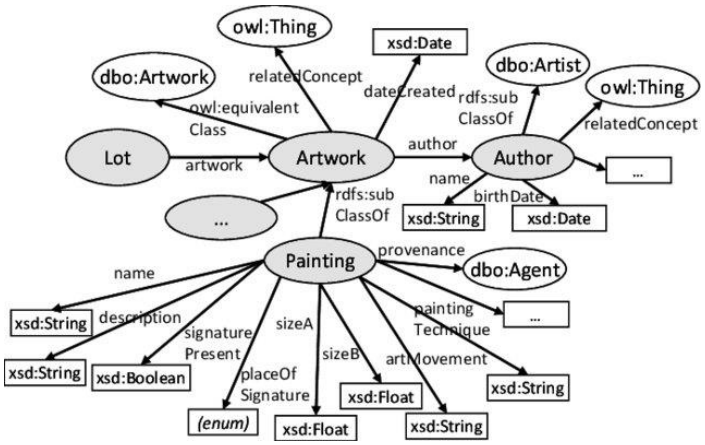

Figura 2. Excerpt of the art auction ontology, artwork data (from Filipiak et al. 2016)

The former fragment is particularly relevant as it stresses the importance of not directly linking the artwork to the sales, rather the model relies on the intermediate class of *lot*, the "central entity" of the shown part of the ontology, in which "a particular item is offered for sale" ([11]: 6). Nonetheless, the project seems to consider only a specific situation, consisting of artworks by a known author (see Figura 2), omitting other crucial practices of this domain (such as evaluations or expertises), which are instead important in the definition of the exchange value of the single object.

The current state of the art hence now lacks a consistent and comprehensive data model which enables the interaction between current standard modules used to describe objects, event, and agents. On top of that, the new ontology will be indeed asked to define both relevant practices of the art historical domain and to state relevant archival and bibliographical sources, in order to support and streamline future researches of this sector.

Towards the Art Market Ontology

Methodology

As said, the "Art Market Ontology" is intended to build up meaningful relationships among different elements of the art market and the art-historical scholarships. Such a broad ontology hence needs to be subdivided into minor modules; in particular, three main domains have been defined.

The first one is focused on the agent (i.e., the art dealer) and describes the possible relations connecting a single person to an organization (e.g., the art gallery or the auction house). The second module is focused instead on the artwork and the agent in the context of the transaction: the various kinds of economic exchanges are taken into consideration and special attention has been paid to the analysis of value attribution processes (authorship attribution, expertise, and value proposition). Lastly, the third module scrutinizes the documentary sources on which art

historians rely to reconstruct the activity of art dealers. As discussed in the following paragraphs, they consist of either single objects or entire curated holdings, such as archives.

The following ontology will be developed relying on SAMOD methodology ([19]):

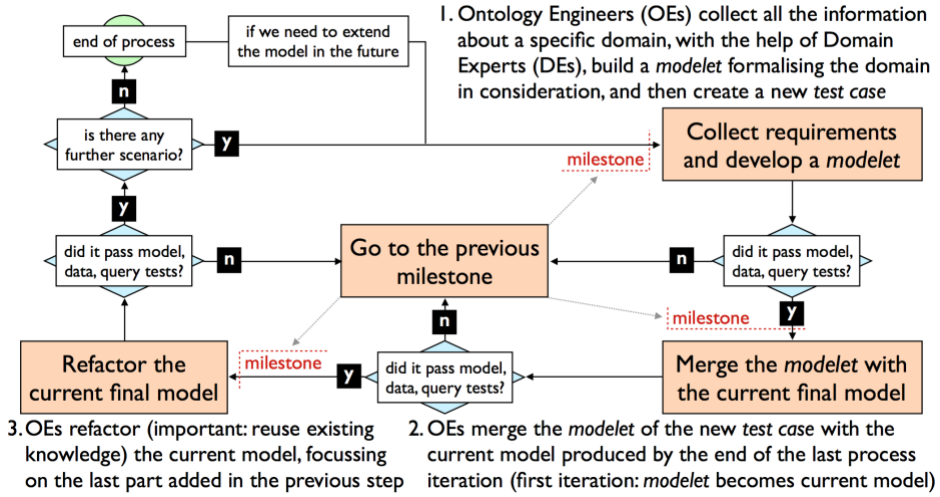

Figura 3. SAMOD Methodology after Peroni ([19])

Indeed, the acronym SAMOD stands for *Simplified Agile Methodology for Ontology Development* and is based on an iterative process in which a "domain expert" (DE) and "ontology engineer" (OE) collaborate to define motivating scenarios, which are small problems defined in natural language and associated to a set of informal and likely examples. After this first step, competency questions are formulated. On this basis, the OE develops a standalone *modelet* and refractors it to check "formal" and "rhetorical" requirements, that is mainly to verify the absence of inconsistencies and to compare the solutions of the SPARQL competency questions with the expected results.[1]

Due to time constraints, the SAMOD methodology has been slightly revised, as at first the motivating scenarios and the competency questions have been defined with the DEs for all the foreseen iterations, in order to collect in advance all the necessary material for the construction of the single modelet. The following paper will hence propose a preliminary analysis, scrutinizing the collected materials: in particular, this essay is aimed at both identify in the possibilities of a direct reuse of existing ontologies, especially CIDOC-CRM ([4]), and at proposing the necessary integrations.

These reflections will serve as guidelines in the proper construction of the ontology, whose responsibility lies entirely with the OE. Indeed, also the remaining steps of the SAMOD methodology are to be implemented. Firstly, the *modelets* will be drawn with the software *yEd*[2] using the graphical framework *Graffoo*.[3] The model will be later converted into .owl file with the

[1] See SAMOD guidelines ([19]) for a more detailed description of this methodology.

[2] yWorks. *yEd*. https://www.yworks.com/products/yed.

[3] Peroni, Silvio. *Graffoo*. https://essepuntato.it/graffoo/. See Falco et al. ([10]).

tool *Ditto*[4] and populated in *Protégé*.[5] Fulfilment of formal requirement will be checked both in this software, with the reasoner *HermiT*,[6] and with *OntOlogy Pittfall Scanner* (*OOPS!*).[7] After populating the ontology with the example dataset, the plug-in *SPARQL Query*[8] installed in *Protégé* will be used to verify the correctness of the answers to SPARQL-format competency questions. On the contrary, in the test case phase, rhetorical requirements of model, data, and query tests (*bag of test cases)* will be checked manually. Table 1 sums up the used design tools, associating them with the corresponding step of the SAMOD methodology:

SAMOD Step	**Tool**
Building of the modelet • Graphical representation • OWL serialization	 Graffoo DITTO
Model test, formal requirements	Protégé – HermiT Reasoner OOPS!
Building of the dataset according to the developed modelet	Protégé
Data test, formal requirements	Protégé – HermiT Reasoner
Query test, formal requirements	Protégé – SPARQL Query

Table 1 Tools for ontology design compared with the various stages foreseen by SAMOD

As foreseen by SAMOD methodology, modelet merging and milestones releasing will be admissible only in case the requirements stated by the bag of test cases are met.

Modules

As mentioned, the domain will be subdivided into three core modules, which will be iteratively described through sets of motivating scenarios, relevant examples[9] and competency questions. These structures will be presented and analyzed in the following paragraphs and will be commented on using existing ontologies as references.

[4] Peroni, Silvio. *DITTO*. https://essepuntato.it/ditto/. See Gangemi and Peroni ([14]).

[5] Stanford University, School of Medicine, Stanford Center for Biomedical Informatics Research. *Protégé*. https://protege.stanford.edu/.

[6] Oxford University, Department of Computer Science, Data and Knowledge Group - Knowledge Representation and Reasoning. *HermiT OWL Reasoner*. http://www.hermit-reasoner.com/. Reference version: HermiT 1.4.3.456.

[7] Ontology Engineering Group. *OntOlogy Pitfall Scanner*. https://oops.linkeddata.es/. See Poveda-Villalón, Gómez-Pérez, and Suárez-Figueroa ([21]).

[8] Redmond, Timothy. *SPARQL Query*. https://protegewiki.stanford.edu/wiki/SPARQL_Query.

[9] The examples enable to analyze the reference scenarios through practical case studies. Nonetheless, they are fictious and any reference to people, organizations and events is to be considered purely coincidental.

Agents

This module is intended to describe the art dealer activity when carried out both by a private individual and by a complex and structured organization, such as an auction house. The first motivating scenario hence provides a first overview:

1.1 General overview of the main agents in the art market	
Motivating scenario	An art dealer activity can be carried out by either a person, specialized in a particular discipline, or an organization, which can be of various types, including an auction house, and has a person in charge (managing director). There may be people and organizations that do not carry out an art dealer activity but are nevertheless involved in the cultural industry.
Examples	1. SR, specialized in Mannerist painting, is in charge of the auction house "Antichità". 2. MF, specialized in Baroque sculpture, oversees the art gallery "Beaux Arts". 3. BV is the director of "Universo mostre", an organization which cannot be considered properly as an art dealer, albeit it operates in the artistic sector.
Competency questions	1. Who is the managing director of the auction house "Antichità"? (SR) 2. In which field is the managing director of "Beaux Arts" specialized? (Baroque sculpture) 3. Are there organizations which are not art dealers? (Yes, BV's "Universo mostre")

Table 2. First iteration of the module "Agents": motivating scenario, examples, and competency questions

This first presentation already permits us to identify the most relevant entities and properties involved. The scenario indeed already paves the way to a possible alignment with both CIDOC-CRM (from now on, crm:) and *Org*: the main class, which gives the name to the entire module, is indeed "Agent", which is to be modeled as superclass of both "Person" and "Organization". Albeit the definition of these entities might be intuitive, due to the typology of actors involved in the art market, it is advisable that the last class would be associated with org:Organization, consequently with a narrower semantics than crm:E74_Group. Indeed, it will not comprise unstructured and unorganized gatherings of human individuals.

Moreover, the requirements stated by the scenario and the competency questions indicate as necessary a more detailed description of the class "Organization". Even though the majority of its subclasses will be introduced in the following scenarios, it is still possible to introduce "ArtDealerOrganization", which is in turn superclass of "AuctionHouse". If the latter is already defined by the ontology developed by Filipiak (see *supra*), existing models seem to provide either semantically broader and narrower concept, but lack of a specific class to define agents (or "actors", as formulated by CIDOC-CRM) who play an active role in exchange, conservation, creation and restoration of the objects who are destined to the art market.

On the other hand, the involvement in the art market cannot be a sufficient criterion to differentiate also the entity "Person" in two subclasses. As a matter of fact, an organization is founded with a specific scope, while an individual can be active in more than one domain and not mandatorily at the same time. "Person" class instances' activity should be hence considered as a role and should not be defined by instantiating an individual of a specific subclass, rather it could be inferred by the participation to specific events (see second module). The scenario instead requests to better define the education and specialization of the single person: in this case this domain of knowledge can be modeled as a separated class which can be aligned with the FABIO (https://sparontologies.github.io/fabio/current/fabio.html) class (from now on, fabio:) fabio:SubjectDiscipline. The definition of the role within the organization will instead be analyzed in an *ad hoc* scenario (no. 1.4), devoted to the possible collaborations an art dealer may establish during his activity.

The second and the third scenarios are instead focused on the creation, the modification, and the cessation of the art dealer activity.

1.2 Possible different organizations of an art-dealer company	
Motivating scenario	The company is defined by a foundation, which establishes the involved actors, the name, the location, the date, and the type of activity. Several companies may refer to the same family venture, which indicates all business activities owned by the members of the same family. The company may open new branches and laboratory.
Examples	1. The art dealer ST, after opening the "Arti d'Urbe" gallery in Rome, Piazza delle Erbe, in 1949, opened a restoration laboratory in Rome, Piazza Navona, in 1956. 2. The art dealer CP opened a second branch of the *Galleria* "Artimercato" in Florence in Via dei Fossi in 1977. 3. LZ and PS founded a gallery together in Rome in 1980 under the name "Arti libere".
Competency questions	1. Which activities did ST found? ("Arti d'Urbe", 1949, Piazza delle Erbe, Rome; P.za Navona, Rome, ST, 1956) 2. Which are all the business activities referable to the P. family? ("Artimercato", n.a., Milan; n.a., 1977, Via dei Fossi, Florence) 3. What are the activities in Rome between 1950 and 1985? ("Arti d'Urbe", P.za delle Erbe, Rome, ST, 1949; n.a., P.za Navona, Rome, ST, 1956; "Arti Libere", Roma, LZ and PS, n.a.)

Table 3. Second iteration of the module "Agents": motivating scenario, examples, and competency questions

Compared to the previous one, this scenario is intended to describe the main relationships between the single person and the art dealer organizations and its subclasses. On the one hand, it describes a quite common dynamic in the art market domain, i.e., the presence of different secondary activities (i.e., branches) which can refer to the same main organization. Among these,

restoration laboratories also play a relevant role. For example, as analyzed by Mambelli in the commercial venture of Sangiorgi ([18]), the presence of an *ad hoc* venue to restore artefacts and create in-style reproductions was a crucial sector of his antiquarian activity. Existing conceptual models, such as the Organization Ontology, are able to describe the hierarchical relationship between two organizations thanks to org:hasSubOrganization (and the inverse, org:subOrganizationOf), although a new class should be introduced to describe laboratory. Being subclass of org:Organization and of crm:Group, the activity of restoration and production does not need to be described in this model, rather it can be delegated to CIDOC-CRM, in particular through the classes crm:E11_Modification and crm:E12_Production.

The distinction between different interrelated organizations lead to necessity to also describe the geographical and chronological extent of the activity. This goal was pursued by the reuse and the enrichment of the triple "org:Organization org:hasSite org:Site". In the Organization ontology, the site is associated with a physical location, defined by an address. Nonetheless, it is often difficult to precisely reconstruct this piece of information for the organizations operating in the art market, due to both a lack in the sources and the fact that the toponymies might change considerably during decades. Consequently, the class Site should be associated with crm:E53_Place. In addition, since this ontology is being thought for supporting scholars in the analysis of the domain, it will be necessary to indicate the time interval during which a seat was active, in order to facilitate historical reconstructions.

Comparing to the existing models, the main introduction is the concept of the familiar venture, which encompasses all the agents, both of class Person and Organization, which belong to the same family across generations. The definition of this high-level entity has been deemed necessary as it has been noted that art dealer companies tend to be handed down through generations of the same family: the importance of this class permits hence scholars to observe and analyze diachronically the evolution of a familiar business, scrutinizing its main protagonists.

Lastly, while the definition of the name and of the business type can be respectively asserted by rdfs:Literal (*RDF 1.2 Schema*, https://www.w3.org/TR/rdf12-schema/) and skos:Concept (*SKOS Simple Knowledge Organization System*, https://www.w3.org/2004/02/skos/), as suggested by Org, the modelling of the opening of the organization should be imported by CIDOC-CRM. Indeed, it already describes this phenomenon through the class crm:E66_Formation and the property crm:P95_has_formed. Similar remarks can be made also for the third iterations, which is indeed focused on the events which characterize the life cycle of a company:

1.3. Events in the life cycle of an art-dealer company	
Motivating scenario	The company can be changed by events (defined by a date and place), such as a change of location and names. The end of a company occurs by cessation of activity or by acquisition by another individual or company.
Examples	1. In 1910 the antiquarian RT was forced to close the gallery "Tesori" in Piazza Duomo, Florence, which has been active since 1870. 2. The auction house owned by SD is bought by MB in 1915. 3. LZ in 1920 changed the name of the business "Arti fiorentine", active in Florence in Via dei Fossi since 1850, to "Les Arts de Paris" when it moved the company to Paris, Champs Élysées.

Competency questions	1. In which period was the RT's organization "Tesori" active? ("Tesori", 1870, 1910, Piazza Duomo, Florence) 2. Who is the buyer of SD's auction house? (MB, 1915) 3. Which events modified ZF's organization? (LZ, 1920, "Les Arts de Paris", Paris, Champs Élysées)

Table 4. Third iteration of the module "Agents": motivating scenario, examples, and competency questions

Following the event-based modeling which characterizes CIDOC-CRM, the scenario can be summed up into two main classes, the first one describing the cessation of activity, while the second one its modification. The former entity is already asserted by the standard ontology, which, in a strict parallelism to crm:E66_Formation, also defines the class crm:E68_Dissolution and the property crm:P99_dissolved. Nonetheless, this class is not able to fully express company purchase: in this scenario, this event is considered a cessation of activity as it causes a change in the reference familiar venture. As a matter of fact, the class crm:E8_Acquisition can be referred only to instances of crm:E18_Physical_Thing due to the range restrictions of P24_transferred_title_of. The new subclass, "CompanyPurchase", will be hence connected to the seller and the buyer to *ad hoc* properties: despite being disjoint by the class "Transaction" of the module event, its set of properties is similar to this latter entity, which will be described in detail when discussing scenario 2.1.

On the contrary, the change of the company cannot be defined by other CIDOC-CRM subclasses: like E8, also crm:E9_Move and crm:E11_Modification can be referred exclusively to crm:E18_Physicial_Thing instances. The Organization ontology, instead, defines this phenomenon through a new class, which can be easily integrated in CIDOC-CRM as subclass crm:E7_Activity (in the class hierarchy, it would be hence at the same depth of E66 and E68): org:ChangeEvent. As shown In Figura 4, this entity connects through specific properties the two individuals, which correspond to the two configurations of the company before and after the modification.

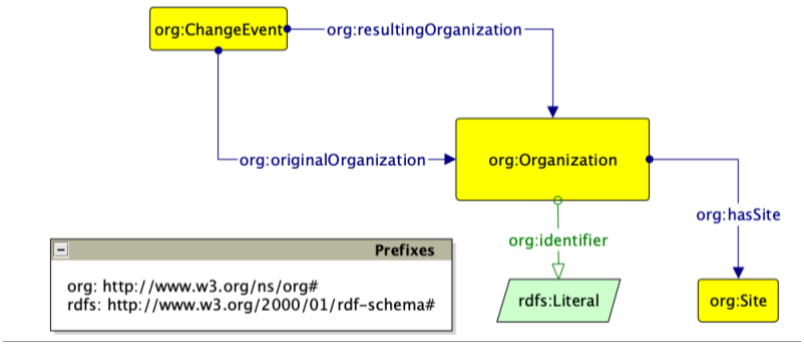

Figura 4: Modelling of org:ChangeEvent. Personal elaboration in Graffoo after Reynolds ([22])

Moreover, the Organization ontology provides fruitful guidelines for the description of the collaboration within a company, which is the focus of the fourth iteration of the module:

1.4. Professional roles and collaborations in the art market

Motivating scenario	An art dealer company relies on various professional roles, covered by an individual or another society, with whom it forges collaboration links defined by a time interval and functional to an event, such as the creation of an object. In addition to the managing director (they can also be more), the main roles are (but not limited to) the reference art historian consultant (who has a background in an art-historical domain; he intervenes in attributions and catalogues), the restorer, the photographer.
Examples	1. The antiquarian GT has several artworks without attribution. He therefore asks AB (a leading expert in the history of the miniature) to collaborate and study these works. This collaboration is occasional and lasts from 1980 to 1982. 2. In order to study the works properly, collaborator AB asks for photographs. Therefore, GT asks photographer AA, with whom he collaborated from 1960 until 1985, to take the photos. 3. FR calls three experts with different skills to draw up a catalogue: GO, a scholar of Baroque sculpture, LA, a scholar of Mannerist painting, AB, a scholar of the history of the miniature. The photographer DD also worked on the catalogue (permanent collaboration). 4. FZ, who had owned the company "Antichità fiorentine" since 1920, died in 1948. The business was continued by his son MZ until 1970. The company was founded by FZ's uncle AQ in 1910.
Competency questions	1. With whom did the art dealer GT collaborate between 1979 and 1985? (Art historian consultant, AB, 1980, 1982; photographer, AA, 1960, 1985) 2. Which photographers are active between 1960 and 2000? (AA, 1960, 1985, GT; DD, n.a., n.a., FR) 3. Who are the art historian consultants who worked with FR to prepare his catalog? (GO, Baroque sculpture; LA, Mannerist painting; AB, History of the miniature) 4. Who are the directors of "Antichità fiorentine"? In which period were they active? (AQ, 1910, 1920; FZ, 1920, 1948; MZ, 1948, 1970)

Table 5. Fourth iteration of the module "Agents": motivating scenario, examples, and competency questions

As a matter of fact, CIDOC-CRM does not provide a specific class to describe the collaborations between two actors, rather it permits to instantiate as event its beginning (crm:E85_Joining) and its end (crm:E86_Leaving). Moreover, apart from crm:E55_Type, the semantic to express the different role is not exhaustive. On the other hand, *Org* provides several classes to model this domain: as stated by the documentation ([22]), each collaboration is defined as in Figura 5:

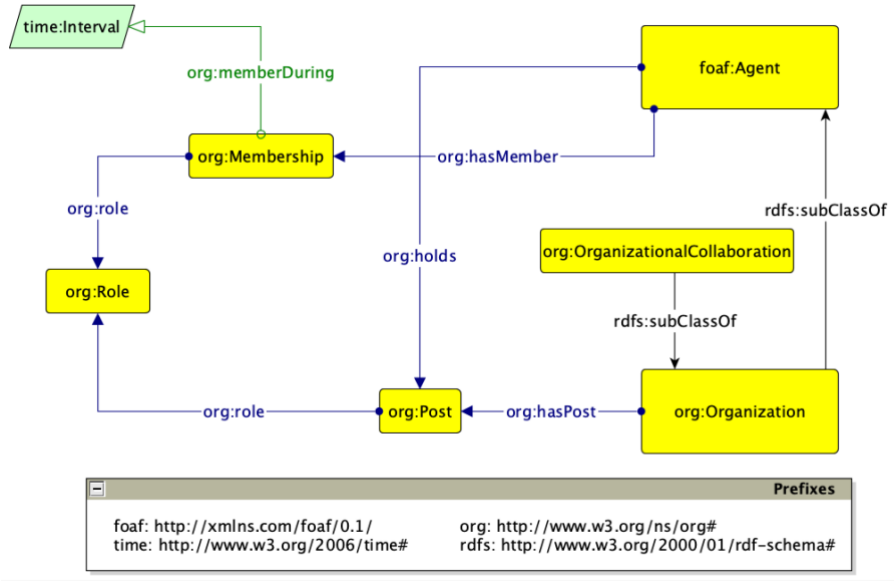

Figura 5: Modelling of the collaboration in the Organization Ontology. Personal elaboration in Graffoo after Reynolds ([22])

The main classes (Membership, OrganizationalCollaboration, Post, and Role) are defined as follows ([22]):

- org:Membership: "Indicates the nature of an Agent's membership of an organization".
- org:OrganizationalCollaboration: "A collaboration between two or more Organizations such as a project. It meets the criteria for being an *Organization* in that it has an identity and defining purpose independent of its particular members but is neither a formally recognized legal entity nor a sub-unit within some larger organization. Might typically have a shorter lifetime than the Organizations within it, but not necessarily".
- org:Post: "A Post represents some position within an organization that exists independently of the person or persons filling it. Posts may be used to represent situations where a person is a member of an organization ex officio (…). A post can be held by multiple people and hence can be treated as [an] organization in its own right".
- org:Role: "Denotes a role that a Person or other Agent can take in an organization. Instances of this class describe the abstract role; to denote a specific instance of a person playing that role in a specific organization use an instance of org:Membership".

Although it provides meaningful suggestions, when applied to the historical reconstruction of the art market, this solution is not completely convincing. Indeed, it combines professional collaboration and membership to associations (which will be discussed in scenario 1.5), differentiates between collaboration with organizations and with single individuals, and separates in two level the covered role and the post inside a company. The data available for art dealer organizations, in particular when they date back to several decades ago, does not always permit to describe the situation in detail. The new ontology, whose main reference users are art historians, should instead be able to define the domain in a more flexible and general approach.

To this end, a possible strategy would involve the creation of new *ad hoc* classes. The first one, "Collaboration", is conceptually related to org:Membership and refers to the fact that two agents have stipulated any form of collaboration or partnership to maximize their own interests. This can be translated also - but not mandatorily - into an employment contract. The two actors involved should be subject of a specific property stating their participation in the collaboration. This last property should be also differentiated into two sub-properties, which enable us to express who has requested and who is providing the service. Following the class hierarchy of *Org*, this entity should not be defined as subclass of events and should relate to a definition of the role, which should be expressed in turn through a controlled vocabulary. With reference to the instructions provided by the motivating scenario, a first nucleus of term shall include the managing director (also mentioned in scenario 1.1), the art historian consultant (whose domain of expertise may be rendered as in scenario 1.1), the restorer, and the photographer.

The class "Collaboration" should also state a time interval and could be associated to a specific purpose, expressed as an individual of type "Event". This solution is harmonized with the reference CIDOC-CRM model: creation of catalogues and photographs, and modification (i.e., restoration) of artworks can be indeed stated by crm:E11_Modification and its subclasses (e. g. crm:E12_Production). The activity of art historian consultant, in particular to what pertains expertise and value attribution, can be instead rendered by the classes introduced in the second module.

As mentioned, this new class does not completely cover the polysemy of *org:Membership*. The participation of a member to an association should be hence described in a separate specific scenario:

1.5. Art dealer organization as member of association and participant to events	
Motivating scenario	A company may participate in several events (location, start date, end date) organized by other agents or organize one at its own premises. The main events are (but not limited to) fairs and exhibitions. Each event can be described by a catalogue. The company can be a member of an association that can promote events.
Examples	1. In 2008, the "Arti belle" gallery organized an exhibition (2008-2009) in Rome. It also participates in the BIF event in Florence, organized by the association "AIT" in 2010 2. The 'AIT' Association regularly promotes the "Artiromane" fair. SA, which has been a member of AIT from 1970 to 1985, participated in this event in 1982 and 1984.

	3. The 'Art' gallery is a member of the "AIT" organization from 1977 to 1988.
Competency questions	1. To which event did "Arti Belle" art gallery participate? ("Arti Belle", Roma, 2008, 2009; BIF, AIT, Firenze, 2010) 2. Which organizations participated in the editions of the event "Arti Romane" between 1981 and 1985? (1982, Roma, AIT, SA; 1984, Roma, AIT, SA) 3. Who are the members of the association "AIT"? (SA, 1970, 1985; *Art*, 1977, 1988)

Table 6. Fifth iteration of the module "Agents": motivating scenario, examples, and competency questions.

As anticipated, the scenario introduces a new subclass of Organization, i.e., "Association", identifying connections or cooperative agreements between agents which stipulated to defend and pursue shared professional interests. The relationship between this class and its members (of type Agent) is mediated by a new class, "Membership", which states a specific time interval (expressed through a data property) and has a more specific semantic comparing to org:Membership as it excludes professional collaborations.

In addition, the scenario mentions other typology of events which characterize the activity of art dealers, such as fairs and exhibitions, which can be specified as subclasses of crm:E5_Event. Nonetheless, a necessary distinction should be made for recurrent events: antiquarian fairs themselves can be included in this case, as each annual edition actually refers to the same series (e.g., The European Fine Art Fair, TEFAF – Maastricht). This distinction in two separated levels has been already tackled by DOLCE (http://ontologydesignpatterns.org/wiki/Ontology:DOLCE+DnS_Ultralite, prefix, dul:), a foundational upper-level ontology (Gangemi et al. 2002). The single recurrent event, besides being aligned with crm:E5_Event, corresponds to dul:Event. On the contrary, the high-level series is actually already expressed by dul:Collection, defined as "any container for entities that share one or more common properties" (Gangemi n.d.). Other typologies of events which directly imply the economic exchange and the definition of the monetary value are instead defined in a separate module, described in the following paragraphs.

Events

The specificity of the art market transactions will be instead treated in this second module. Differently from other types of objects, cultural goods follow specific dynamics from an economic perspective as they do not have an intrinsic economic value. The value (and consequently the price) of each work of art is directly dependent on the discourse, who is principally elaborated by intermediaries. These actors, which may correspond for instance to art historians as author of expertises and attributions, are not directly involved in the economic transaction. Rather, their role is to "translate and convert the symbolic value of artistic creations into economic value through discourse that renders the goods intelligible, acceptable, and valuable" ([16]: 6). Their activity massively impacts both consumers (buyers) and art dealers' organizations, who cultural market theorists assigned to the class of *producers*, as they "have a direct economic interest in the good exchanged in the market because they are involved in its procurement" ([16]: 7). The two scenarios of this module will be hence aimed at summing up the complexity of this domain.

2.1. Art dealer organization as member of association and participant to events	
Motivating scenario	An agent may have ownership and custody (they do not mandatorily match) of an object or a set of artworks. An agent's main activity is the transaction, which include buying (an agent sells an asset in exchange for a sum of money; it changes possession, custody or both), lending (an agent lends an asset in exchange for a sum of money or free of charge, which changes only custody), and donating (an agent gives an asset away free of charge: in this case, both possession and custody change). The asset is defined as a lot and may be a single work or a group of works of art (sometimes even an entire collection). The transaction is identified by at least two parties: one who transfers possession and one who acquires it. A transaction may also have a facilitator.
Examples	1. The antiquarian QC buys the work *Sacra Conversazione* from the private collector ST in 1978 for a sum of €10,000. 2. On the occasion of the exhibition "Neoclassicism" (1980), the antiquarian PP lends a terracotta by Canova to the Museo Civico in Milan. 3. Upon TC's death (1980), his heirs donated their collection to the Museo Civico in Florence. 4. The museum Museo Civico di Belle Arti in Rome bought the painting *Birth of Bacchus* by Giulio Romano from the antiquarian RE in Florence, at the suggestion of the scholar TD
Competency questions	1. When did QC buy the painting *Sacra conversazione*? (1978) 2. Who are the clients of ST? (QC) 3. Who is the last owner of the artworks exhibited at "Neoclassicismo"? (Terracotta by Canova, PP) 4. Who participated in the acquisition of Romano's *Birth of Bacchus*? (Museo Civico di Belle Arti in Rome, buyer; TD, facilitator; RE, seller)

Table 7. First iteration of the module "Events": motivating scenario, examples, and competency questions

The central classes of this scenario are events subclasses and are related to CIDOC-CRM classes crm:E8_Acquisition, its subclass crm:E96_Purchase which involves an exchange of a monetary amount, and crm:E10_Transfer_of_Custody. These classes can be considered subclasses of a broader entity "Transaction" and, as they are not disjoint, it is possible to propose the following alignment with the classes mentioned in the scenario ("Purchase", "Loan", "Gift"):

- "Gift" is intersection of crm:E10 and crm:E8, but disjoint from crm:E96, as it does not foresee an exchange of a monetary amount;

- "Loan" is a subclass of crm:E10;
- "Purchase" should be instead considered as subclass of the union of crm:E96 and crm:E10 (as stated by the scenario, transferal of ownership and of custody might not coincide).

To what pertains the definition of the price, CIDOC-CRM already provides the property cm:P179_had_sales_price, with crm:E97_Monetary_Amount as range. However, the domain of the property is restricted to crm:E96: as a result, the "Art Market Ontology" will introduce a more general super-property "hasPrice", stating as domain the union of "Purchase" and "Loan", since the scenario mentions that also leaning works of art may involve a monetary exchange.

The role of the involved actors can be more generically defined at the level of the new super-class "Transaction" with three properties: "hasSurrender" (potential super-property of crm:P23_transferred_title_from and crm:P28_custody_surrendered_by), "hasReceiver" (potential super-property of crm:P22_transferred_title_to and crm:P29_custody_received_by) and "hasFacilitator", which permits to express the intermediation of a third agent in the transaction. On the contrary the two properties crm:P24_transferred_title_of and crm:P30_transferred_custody_of may not be grouped under a single super-property to underline the difference between a change in the ownership and in the custody. As outlined in the paragraph on the state of the art (Filipiak et al. 2016), they will associate a transaction (according to their domain) with a "Lot" class, which will be hence considered subclass of crm:E18_Physical_Thing. The use of crm:P46_is_composed_of will permit to describe the sold object(s), either of type – again – crm:E18_Physical_Thing[10] or crm:E78_Curated_Holding.

As stated above in the brief overview on the art market, these kinds of events are often preceded by other ones, as described in the last scenario of this module:

2.2. Art dealer organization as member of association and participant to events	
Motivating scenario	The peculiarity of the art market is the fact that the value of an artwork cannot be deduced objectively but depends on multiple external factors. In fact, an agent can value the work independently or by relying on an expert. He reconstructs several characteristics of the work of art. Among these, some important ones are the artefact's authorship (attribution), state of preservation, collecting history (understood as a series of possessions), bibliography. Based on this analysis, an agent proposes a monetary value for the object. Both the attribution and the value proposition can be re-discussed over time by other attributive assignments: all these events influence (without necessarily coinciding) the real price of the transaction. The asset may be subject to notification (usually not withdrawn but may only be valid for a certain amount of time) by the State and this affects the value of the asset.

[10] Albeit the ontology primarily deals with artworks, the domains stated by crm:P46 will be maintained unchanged as historical collections may also contained instances of crm:E18 which are not man-made (hence, not product of a crm:E12_Production activity).

Examples	1. In 2001, the antiquarian PT calls the reference scholar SB to have him study a 17th century painting (*San Rocco*). He attributes the artwork to Guido Reni. 2. In 2005 SB studies a *Deposition* attributed to Guido Reni: after some research he attributes it instead to Domenichino. 3. The antiquarian SZ owns a painting by Tintoretto, whose value in 1980 was €15,000 because a previous appraisal showed it to be in a good state of conservation and the work is mentioned in the catalogue *Le opere di Tintoretto*. 4. Based on the analysis of Tintoretto's canvas by the scholar ML, commissioned by SZ, it was discovered that the work was owned by Count F. SZ put it on sale in 1990 at the equivalent cost of 35,000€ and at 30,000€ in 1991. 5. The work *San Rocco* by Guido Reni was notified in 2008 by the Italian State.
Competency questions	1. Which artworks did SB study? (*San Rocco*, Guido Reni, 2001; *Deposizione*, Domenichino, 2005) 2. Which are the different value attributions of the canvas by Tintoretto? (1980, 15000€; 1990, 35000€; 1991, 30000€) 3. Are there artworks under notification? (Yes: *San Rocco*, 2008, owned by PT)

Table 8. Second iteration of the module "Events": motivating scenario, examples, and competency questions

The two main events mentioned in the scenario can be modeled as two separated subclasses of crm:E13_Attribute_Assignment. As subclass of crm:E7_Activity and crm:E5_Event, the professional collaboration and partnerships involved can be stated following the model defined in scenario 1.4. The first entity, "Expertise", concerns the expertise made by the art historian and is aimed at identifying author and previous owner, at diagnosing the conservation state, with the support of different source. CIDOC-CRM already proposes a solution to states these elements, using the combination of:

```
crm:E13_Attribute_Assignment crm:P11_had_participant crm:E39_Actor.
crm:E13_Attribute_Assignment        crm:P140_assigned_attribute_to
crm:E1_CRM_Entity.
crm:E13_Attribute_Assignment crm:P141_assigned crm:E1_CRM_Entity.
crm:E13_Attribute_Assignment     crm:P177_assigned_property_of_type
crm:E55_Type.
```

The most relevant peculiarities of the "Expertise" have been already modeled by the HICO, the Historical Context Ontology (Daquino and Tomasi 2015), which is centered on the class hico:InterpretationAct, as shown in Fig 6:

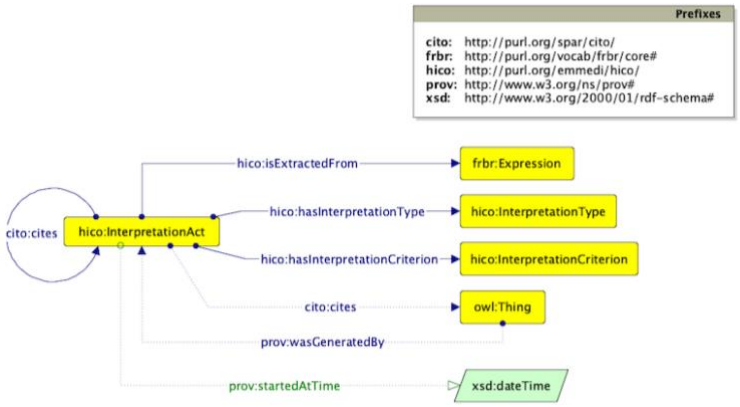

Figura 6: HICO Conceptual model

Defining "Expertise" as subclass of both hico:InterpretationAct and crm:E14_Condition_Assessment permits to state all the different attributes mentioned by the scenario. Indeed, ownership and authorship can be defined as distinct hico:hasInterpretationType (the documentation, https://marilenadaquino.github.io/hico/, already provides on example of author attribution based on the dataset of Fondazione Zeri Photo Archive) and the conservations status can be expressed as crm:P35_has_identified crm:E3_Condition_State.

In addition, the use of CITO ontology (https://sparontologies.github.io/cito/current/cito.html), whose properties do not contain domain and range restrictions has been removed after v1.6 (Peroni and Shotton 2012, 40), permits to state with several semantical nuances both supporting sources (here considered as instances of crm:E24_Physical_Human-Made_Thing) and relationships between different events of type of crm:E13 (in this model, both "Expertise" and "ValueAttribution"). This latter use case expresses for instance agreements and disagreements among different agents studying the same objects. Moreover, it also permits to express a causality nexus between "Expertise" and "ValueAttribution", the second subclass of E13 introduced by the scenario. On the basis of the assessments made in the former event, a monetary evaluation of the work of art can be proposed. Similarly to definition of the attributed author, the proposed price can be stated with another sub-property of crm:P141, such as "hasProposedPrice", with crm:E97_Monetary_Amount as range.

Lastly, the scenario also introduces the possibility of having legal constraints on the event. With reference to Italian legislative system, one of the most famous examples is the "notifica" (ex d.lgs. 22 gennaio 2004, n. 42, c.d. *Codice dei beni culturali e del paesaggio*). This act recognizes the value cultural, artistic, historical, or ethno-anthropological interest of cultural artefacts (included collections, hence generically of crm:E18_Physical_Thing) and limits their circulation. CIDOC-CRM already provides a framework to describe this phenomenon, i.e. crm:E30_Right. The properties in which this class is involved permit to state limit on instances of class "Transaction". As:

```
crm:E50_Right crm:P67_refers_to crm:E1_CRM_Entity.
crm:E7_Activity crm:P15_was_influenced_by crm:E1_CRM_Entity.
```

It would be indeed possible to assert the following axioms:

```
crm:E50_Right crm:P67_refers_to crm:E18_Physical_Thing.
:Transaction crm:P15_was_influenced_by crm:E50_Right.
```

Sources

The last module of the "Art Market Ontology" pertains the use of sources for the historical reconstruction of the activity of the main protagonists of the art market. It consists of a single iteration as it is already possible to model sources thanks to existing ontologies. The scenario will hence mention only the most frequently used documents to reconstruct this domain and will pay attention to the most generic properties which associate a source with the event or the agent they refer to.

3.1. Sources for the historical reconstruction of the art market	
Motivating scenario	Objects may mainly (but not only) be bibliographic (comprising various types, including catalogues) or archival item (such as, but not limited to, account ledgers, receipts, letters, photos) and works of art; they may be contained within a curated holding (library, archive, including photo archive, or art collection; they may have extension indications) which is identified by a current owner (an agent) and which may in turn be contained by another holding. These elements can be used as sources for events or agents: some of them are precipitates of the agent's activity (primary source), while others are the result of later studies (secondary source).
Examples	1. The archival collection of the antiquarian GT, comprising 600 photos and 300 letters from 1940 to 1990, is now owned by the SZ Foundation. 2. The "Art Institute" research center owns KG's archive, which contains several primary sources, such as receipt #KG1950 from the sale of a predella by Gentile da Fabriano and a letter to SZ. 3. There is also KG's autobiography *My life*, the unpublished manuscript of which is now in the possession of the heir FG 4. There are also secondary sources on KG: the volume *KG: An Ar Collectionist* and the website *KG on the web*.
Competency questions	1. Who is the owner of GT's archive? (Foundation SZ)

	2. Which are the sources which can be used to reconstruct the life and the activity of KG? (KG's archive, "Art Institute"; Receipt #KG1950, "Art Institute"; Letter to SZ, "Art Institute"; *KG. My life*, FG; *KG: An Art Collectionist*, n.a.; *KG on the web*, n.a.)

Table 9. Main iteration of the module "Sources": motivating scenario, examples, and competency questions

Sources can be considered generically instances of the subclasses of crm:E18_Physical_Thing, in particular two crm:E22_Human-Made_Object and crm:E78_Curated_Holding. Nonetheless, the scenario introduces the need for further taxonomizing these super-classes. For instance, the latter one can be subdivided into art collections, libraries, and archives (with the subclass concerning photo archives), in parallelism with the standard classification of LAM institutions. They can be rendered as new specification of crm:E78; moreover, they are also to be considered subclasses of fabio:WorkCollection, which enables the interoperability with the F Entry ontology ([5]).

On the other hand, potential subclasses of crm:E22 could help in a more precise alignment. Table 10 proposes a first solution to this challenge and lists the element into three hierarchical levels (subclasses are identified by indentation). The root note, crm:E22, is subdivided into three macro-categories which reflect the tripartition of the subclasses of crm:E78. The third level mentions the most common sources on which scholars may rely for their historical reconstructions: this list, therefore, is not conceived to be exhaustive, rather it reflects most common academic praxes. In particular, "ArchivalItem" contains those objects which are usually conservated by archives, such as letters and photographs. Moreover, the study of economic exchanges is also possible thanks to account registers, on which an agent may have listed his own belongings, and the receipts of the transactions (e.g., the records of the activity of Kleinberger Galleries Inc. at Watson Library – The Metropolitan Museum of Art in New York[11]).

Similarly, bibliographical sources are grouped under the class "BibliographicItem". It contains a sole child class, catalog, which has been declared due to its undeniable importance art historical analysis. Other kinds of publications can be instantiated relying on the rich taxonomy provided by FABIO. The justification of this alignment is rooted in the solutions adopted during the exposure in RDF of the F ([5]) and OA entry ([6]). The sole integration was the use of RICO (Records in Contexts Ontology), the International Council of Archives standard ontology for the description of "Archival Items".

crm:E22_Human-Made_Object	fabio:AnalogItem
Artwork	fabio:ArtisticWork
ArchivalItem	rico:Instantiation
AccountRegister	
Receipt	
Photo	fentry:Photograph

[11] See https://cdm16028.contentdm.oclc.org/digital/collection/p16028coll23/search.

Letter	fabio:Letter
BibliographicItem	
Catalog	fabio:Catalog

Table 10. Alignment of the subclasses of crm:E22.

Another specificity of the domain is the need to use oral sources, such as interviews, to clarify aspects not reported by documents or bibliography. The modelling of these sources cannot rely exclusively on crm:E22, as they do not have *per se* "physical boundaries that separate them completely in an objective way from other objects". On the contrary, the re-use of the WEMI conceptual model, translated into OWL by FABIO, allows to elude this problem thanks to the use of fabio:Work class. Through the property fabio:hasPortrayal, this entity can be associated to a specific instance of fabio:Item. This last class can be aligned with the crm:E22 to express the possibility of conserving the interview on a support (either analog or digital), which can be in turn included in a curated holding.

Lastly, the relationship between a source and the entity or the actors (i.e., with an owl:Thing instance) it documents should be mediated by a third class, defined by HICO ontology (also used in F and OA entry). An historical reconstruction can indeed be questioned, and it can be contextualized in a specific and well determined chronotope: it therefore coincides with hico:InterpretationAct. As shown in Figura 6, this class is domain of cito:cites and its subproperties, such as cito:citesAsEvidence. The distinction between primary, which identifies sources produced during the historical period they refer to, and secondary sources, relying on primary ones, may be asserted through new sub-properties of this class. In addition, the class hico:InterpretationAct can be aligned to frbr:Endeavour, which is in turn equivalent also to frbr:Work. This permits to state the subject of the historical reconstructions through the follwing axiom, where frbr:Subject refers to an arbitrary set of entities:

```
frbr:Work frbr:subject frbr:Subject
```

Discussion

In the creation of the Art Market Ontology, we chose to bridge and integrate existing models, such as that of Filipiak and colleagues or the *Organization Ontology*, which alone would not have made it possible to describe such a multifaceted domain. Furthermore, the ontology is intended to be interoperable with ICOM's standard model, CIDOC-CRM, and is also designed for future full integration with the existing RDF datasets of the Zeri Foundation, as a systematic reuse of the RDF models of the F and OA Entry has been made.

At this propaedeutical stage, some limitations can yet be identified. As a matter of fact, this project provides a first general description of the art market, able to describe the most relevant dynamics of this sector. Some minor peculiarities of a single event, of a particular agent or source might hence be omitted in the serialization of the knowledge graph, as they were not foreseen in the original motivating scenario. For each of the three modules into which it is subdivided, one could certainly include other interactions and investigate more refined aspects and relationships linking art market-related entities.

The analysis of the research field started and remained closely linked to the contents of Federico Zeri's archive and the database that resulted from its cataloguing. In order to test its validity, it will certainly be necessary not only to take into consideration specific cases that the Foundation has deepened over the years in monographic studies, but also to apply it to datasets built by other research institutes active in the sector.

In this perspective, opening the discussion with renown art-historical research centers mentioned in the Introduction, such as ZADIK, the Bloomsbury Digital Resources, the Getty Research Institute or The International Art Market Studies Association would be for sure be beneficial: comparing the different approaches and data structure of similar centers would allow art-historians and ontology engineers to capture with greater precision the peculiarities of this sector and could provide a number of further case studies for testing the model.

A further limitation concerns the specific nature of the sources used to explore the field of research. Catalogs, archival documents, and oral histories can sometimes deliberately conceal or distort certain details about business transactions. When collecting or using information about art market dynamics, scholars often have to deal with ambiguous, partial, or incomplete data. The ability to effectively express the possible inconsistencies, without this bias undermining the validity of future research, remains one of the goals of the model, which has yet to be tested.

Conclusions and further works

The article presents a preliminary analysis of an ongoing project aimed at defining an ontology of the art market. It stems from the increasing attention received in recent years by art market studies and from the long-standing research activities of the Federico Zeri Foundation. Beginning with the evidence collected in the Archives and Photo Library, it has been engaged for years in collecting information concerning mainly antiquarians active in Italy between the nineteenth and twentieth centuries. It is therefore already in possession of very refined data on some of the market protagonists that can offer a good sample to verify the correct functioning of the model. At the same time, the Foundation has recently promoted two research grants for scholars who are conducting a thorough analysis of aspects and protagonists of the market in this same chronological and temporal span. This is producing a significant amount of *ex-novo* data, coming from multiple sources, which must be recorded, systematized, and integrated with other resources available on the web.

Besides providing a recognition of existing conceptual models, the paper reconstructs the reference domain relying on the competency questions, examples and motivating scenarios defined by the first iterations of the SAMOD Methodology. These materials laid the basis for the identification of the most relevant entities and properties, which were modeled both through systematic reuse of existing models and with the implementation of necessary integrations.

After the finalization of the ontology, the next steps include populating the Art Market Ontology proposed with some case-tests part of the Fondazione Federico Zeri dataset, and establishing a fruitful dialogue with other research institutions that are creating authority files or other digital resources dedicated to this field.

The development of the ontology does not only satisfy the need to organize systematically the pieces of information gathered thanks to traditional methodologies of art historical research. It will hopefully show also how digital art history and knowledge organization practices can guide research even in the data collection phase, leading to the production of rich, well-structured, and integrable dataset, so to offer new strategies to further deepen the knowledge of the art market sector.

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References

[1] Bacchi, Andrea, and Giovanna Capitelli. 2020. *Capitale e crocevia. Il mercato dell'arte nella Roma sabauda*. Vol. 8. Fondazione Federico Zeri-Silvana Editoriale.

[2] Bloomsbury. n.d. 'Bloomsbury Art Markets. Protagonists, Networks, Provenances'. n.d. https://www.artmarketdictionary.com/.

[3] Caraffa, Costanza, and Julia Bärnighausen. 2020. 'Introduction. Photography, Art, Market, and the Production of Value'. *Mitteilungen des Kunsthistorischen Institutes in Florenz* 62 (1): 3–9.

[4] Carriero, Valentina Anita, Marilena Daquino, Aldo Gangemi, Andrea Giovanni Nuzzolese, Silvio Peroni, Valentina Presutti, and Francesca Tomasi. 2020. 'The Landscape of Ontology Reuse Approaches'. In *Studies on the Semantic Web*, edited by Giuseppe Cota, Marilena Daquino, and Gian Luca Pozzato. IOS Press. https://doi.org/10.3233/SSW200033.

[5] Daquino, Marilena. 2016a. 'F Entry to RDF. Mapping the F Entry Italian Content Standard for Cataloguing Photographs to RDF - Version 1.0'. 10.6084/m9.fgshare.3175273.

[6] Daquino, Marilena. 2016b. 'OA Entry to RDF. Mapping the OA Entry Italian Content Standard for Cataloguing Photographs to RDF - Version 1.0'. 10.6084/m9.fgshare.3175057.

[7] Daquino, Marilena, Francesca Mambelli, Silvio Peroni, Francesca Tomasi, and Fabio Vitali. 2017. 'Enhancing Semantic Expressivity in the Cultural Heritage Domain: Exposing the Zeri Photo Archive as Linked Open Data'. *Journal on Computing and Cultural Heritage* 10 (4): 1–21. https://doi.org/10.1145/3051487.

[8] Daquino, Marilena, and Francesca Tomasi. 2015. 'Historical Context Ontology (HiCO): A Conceptual Model for Describing Context Information of Cultural Heritage Objects'. In *Metadata and Semantics Research*, edited by Emmanouel Garoufallou, Richard J. Hartley, and Panorea Gaitanou, 544:424–36. Communications in Computer and Information Science. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-24129-6_37.

[9] Doerr, Martin, and Heraklion Kritsotaki. 2006. 'Documenting Events in Metadata'. In *VAST: International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage*, edited by Marinos Ioannides, David Arnold, Franco Niccolucci, and Katerina Mania. The Eurographics Association.

[10] Falco, Riccardo, Aldo Gangemi, Silvio Peroni, David Shotton, and Fabio Vitali. 2014. 'Modelling OWL Ontologies with Graffoo'. In *The Semantic Web: ESWC 2014 Satellite Events*, edited by Valentina Presutti, Eva Blomqvist, Raphael Troncy, Harald Sack, Ioannis Papadakis, and Anna Tordai, 8798:320–25. Lecture Notes in Computer Science. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-11955-7_42.

[11] Filipiak, Dominik, Henning Agt-Rickauer, Christian Hentschel, Agata Filipowska, and Harald Sack. 2016. 'Quantitative Analysis of Art Market Using Ontologies, Named Entity Recognition and Machine Learning: A Case Study'. In *Business Information Systems*, edited by Witold Abramowicz, Rainer Alt, and Bogdan Franczyk, 255:79–90. Lecture Notes in Business Information Processing. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-39426-8_7.

[12] Gangemi, Aldo. n.d. 'DOLCE+DnS Ultralite Documentation, v. 3.34'. n.d. http://www.ontologydesignpatterns.org/ont/dul/DUL.owl.

[13] Gangemi, Aldo, Nicola Guarino, Claudio Masolo, Alessandro Oltramari, and Luc Schneider. 2002. 'Sweetening Ontologies with DOLCE'. In *Knowledge Engineering and Knowledge Management: Ontologies and the Semantic Web*, edited by Asunción Gómez-Pérez and V. Richard Benjamins, 2473:166–81. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/3-540-45810-7_18.

[14] Gangemi, Aldo, and Silvio Peroni. 2013. 'DiTTO: Diagrams Transformation into OWL'. In *Proceedings of the ISWC 2013 Posters & Demonstrations Track*, 1035:5–8. CEUR Workshop Proceedings. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84924705694&partnerID=40&md5=479affbb65f3508aab864416b1dc2dca.

[15] Guizzardi, Giancarlo, Glenda Amaral, Daniele Porello, and Tiago Prince Sales. 2020. 'A Core Ontology for Economic Exchanges'. In *Conceptual Modeling: 39th International Conference, ER 2020, Vienna, Austria, November 3–6, 2020, Proceedings.*, 364–74.

[16] Khaire, Mukti. 2017. *Culture and Commerce: The Value of Entrepreneurship in Creative Industries*. Stanford, California: Stanford Business Books, an imprint of Stanford University Press.

[17] Mambelli, Francesca. 2014. 'Una risorsa online per la storia dell'arte: il database della Fondazione Federico Zeri'. In *Digital Humanities. Progetti italiani ed esperienze di convergenza multidisciplinare*, 113–25. Roma: Sapienza Università Editrice.

[18] Mambelli, Francesca. 2020. '"Il più grande centro commerciale di oggetti d'arte": la galleria Sangiorgi tra strategie di marketing e artigianato artistico'. In *Capitale e crocevia. Il mercato dell'arte nella Roma sabauda*, by Andrea Bacchi and Giovanna Capitelli. Cinisello Balsamo: Silvana Editoriale.

[19] Peroni, Silvio. 2016. 'SAMOD: An Agile Methodology for the Development of Ontologies'. In *Proceedings of the 13th OWL: Experiences and Directions Workshop and 5th OWL Reasoner Evaluation Workshop (OWLED-ORE 2016)*, 1–14.

[20] Peroni, Silvio, and David Shotton. 2012. 'FaBiO and CiTO: Ontologies for Describing Bibliographic Resources and Citations'. *Journal of Web Semantics* 17 (December): 33–43. https://doi.org/10.1016/j.websem.2012.08.001.

[21] Poveda-Villalón, María, Asunción Gómez-Pérez, and Mari Carmen Suárez-Figueroa. 2014. 'OOPS! (OntOlogy Pitfall Scanner!): An on-Line Tool for Ontology Evaluation'. *International Journal on Semantic Web and Information Systems (IJSWIS)* 10 (2): 7–34.

[22] Reynolds, Dave. 2014. 'The Organization Ontology'. W3C Recommendation. https://www.w3.org/TR/vocab-org/.