R&D networks in high technology applied to cultural goods in Tuscany. A social network analysis[1]

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Luciana Lazzeretti - Francesco Capone

Abstract

***Purpose of the paper**: The aim of this research is to investigate the relationship dynamics of innovation networks in the business of High Technology applied to Cultural Goods (HTCG) in Tuscany, in order to analyze the relevance of the actors' position and their centrality in the networks. The study contributes to the wide research strand on the importance of network competences and relational capabilities for innovation.*

***Methodology**: Social Network Analysis is applied to 42 R&D projects developed by local actors in Tuscany along fifteen years, funded at regional, national and international levels.*

***Findings**: The results show that the business of HTCG is a complex business, where inter-organizational relationships are developed among Triple Helix actors in public-private partnerships and industry-university relationships.*

***Research limits**: The research adopts a quantitative approach to the study of relationship dynamics in innovation networks and uses the Social Network Analysis. In this context, the analysis of temporary R&D projects is restricted to the results concerning the dynamics of temporary networks and exclusively for formal collaborations. In addition, the research would benefit from some in-depth interviews in order to investigate how and why actors develop relationships and with whom.*

***Practical implications**: It is therefore necessary to underline the importance for managers of relational competences for innovation and the relevance of resources and competences also outside the firm's boundaries, in particular in a complex business like HTCG.*

***Originality of the paper**: The work is a preliminary, but original study on HTCG and it depicts several figures on network dynamics in this newly emerging business.*

Key words: network; high technology; cultural heritage; Tuscany; social network analysis

1. Introduction

The sources of innovation are more often found rather between firms, universities, research laboratories, suppliers and customers than inside them (Van der Valk and Gijsbers, 2010; Chesbrough, 2003; Von Hippel, 2005). Firms engage in cooperation not only to share the costs and risks of research

[1] This study was conducted within the 2014 project 'Tecniche avanzate per la conoscenza materica e la conservazione del patrimonio storico-artistico' (Regione Toscana, POR-CreO/FESR, 2007-2013) coordinated by IFAC-CNR.

activities but also to obtain access to new markets and technologies and make use of complementary skills (Hagedoorn *et al.*, 2000; Kogut, 2000; Pyka, 2002).

This paper presents the results of a study on High Technology applied to Cultural Heritage (HTCH) in Tuscany through the analysis of R&D projects aiming at the application of new technologies to the safeguard, restoration and enhancement of artistic and cultural goods.

The research deals with high technology applied to cultural goods as a sector on which increasing attention has been paid both from a research perspective and for its policy relevance and business opportunities (Chapuis, 2009; IRPET, 2012; Casprini *et al.*, 2014; Bifulco, 2009; Di Pietro *et al.*, 2014). What concerns us is to investigate the research field and the economic activity that relies on high technology applicable to the cultural heritage (High Technologies applied to Cultural Goods, from now on referred to with the acronym HTCG).

The study fits in the context of recent regional policies aimed at the rationalization of the research and technology transfer system in matter of cultural heritage, through the foundation in 2011 of the "Technology District for Cultural Goods and the Sustainable City" ratified by the resolution n. 539/2011 (Regione Toscana, 2011).

In this context, the aim of this research is to investigate the relationship dynamics of innovation networks in the business of High Technology applied to Cultural Goods (HTCG) in Tuscany, in order to analyse the relevance of the actors' position and their centrality in the networks. The study contributes to the wide research strand on the importance of network competences and relational capabilities for innovation.

Network data are based on joint cooperations in public funded R&D projects financed in over fifteen years (1995-2013) and involving more than 89 M€.

The present study represents the last stage of a long-term research project focusing on the technology cluster for cultural goods in Florence and Tuscany and investigating innovations applied to cultural heritage in Tuscany (Lazzeretti *et al.*, 2011; Lazzeretti, 2012; Lazzeretti and Capone, 2015). The study applies Social Network Analysis (Scott, 2012) to 42 regional, national and international projects in order to identify the key actors in HTCG and the overall network evolution along time.

The results of this work show that HTCG is a complex business, where inter-organizational relationships are developed among actors of the Triple Helix (Etzkowitz and Leydesdorff, 2000), in public-private partnerships and industry-university relationships.

The remainder of the paper is structured as follows. Section 2 introduces the strand of research on networks and innovations, and presents the business of HTCG. Section 3 describes the research design and data sources. Section 4 presents the R&D projects considered in the study, while section 5 focuses on the study of the relationships among actors through the application of Social Network Analysis (SNA). The final remarks synthesize the main results and implications.

2. Networks and high technology for cultural goods in Tuscany

2.1 Networks and innovation

The concept of network in management and business studies originates in the 1980s and has developed very strongly with several strands of research (Lorenzoni and Ornati, 1988; Lorenzoni, 2010; Dagnino *et al.*, 2015)[2]. A sociological approach to networks has developed mainly from the studies of Powell (1990) on intermediate forms between "hierarchy" and the "market". Already Thorelli (1986) in his seminal work pointed out that by building lasting relations with other actors firms can compete efficiently, reducing the costs of transactions (typical of markets) without incurring in large investments (typical of the hierarchical mode of organizing economic activities) (Amit and Schoemaker, 1993; Antoldi *et al.*, 2011).

In management studies, a relevant strand of research has been dedicated to investigate and define strategic networks. Jarillo's work (1988) defines strategic networks as long-term agreements between different, but linked organizations, which allow firms to gain competitive advantages over competitors outside the network.

As Gulati *et al.* (2000, p. 209) wrote: "Strategic networks are composed of inter-organizational ties that are enduring, are of strategic significance for the firms entering them and include strategic alliances, joint ventures, long term buyer–supplier partnerships and a host of similar ties".

After these initial contributions, there has been increasing interest in strategic networks of firms from both academics and policy-makers and from several different disciplines (Pyka 2002; Powell and Grodal, 2005).

Some studies also show that benefits of spatial co-location in a cluster (Porter, 1998) are not equally distributed to all firms, where their amount depends on the position of a firm within the local network (Ahuja, 2000; Zaheer and Bell, 2005). Several studies on industrial districts and clusters discuss the relationship between knowledge networks and clusters, and the firm's position (Bell, 2005; Giuliani, 2013), focusing in particular on the different roles of formal and inform networks (Casanueva *et al.*, 2013).

In the Strategic Network Approach, the interest then focused on the importance for a firm to enlarge its boundaries of strategic intervention to the network of relationships (Zaheer *et al.*, 1998; Gulati, 1999). Besides, some authors underline the relevance of network relationships for constituting a sustainable competitive advantage (Dyer and Sing, 1998; Dagnino *et al.*, 2008; Silvestrelli, 2014) or the role of strategy and relational capability (Capaldo, 2015; Capone, 2014).

This strand of research underlines the relevance of strategic networks and network resources (Gulati *et al.*, 2000), network competences (Ritter and Gemunden, 2003) and organizational or relational capability (Lorenzoni and Lipparini, 1999; Capaldo, 2007). The ability of a single firm to benefit from network resources and acquire new relevant knowledge originates from the interaction of three components: its endowment of unique resources and

[2] Due to the length limit for this work, we refer to the writings of Håkansson and Snehota (1989; 1995) for the perspective taken by the IMP group and the Swedish school on the (industrial) relationships in business networks.

knowledge, its network position, and the structure of the network itself (Zaheer and Bell, 2005). An important strand of research has mainly focused on social capital, trust and network relationships (Zaheer and Venkatraman, 1995; Tsai and Ghoshal, 1998).

Anyway, most researches on networks appear mainly static (Ahuja *et al.*, 2009) as they focus more on network structure than on network process, knowledge flows and network dynamics.

According to the evolutionary perspective, network researches have pointed out that there is a higher propensity for forming ties between actors with similar attributes recalling the concept of homophily (location, age, social status, etc.) (McPherson *et al.*, 2001). Network studies tend to suggest that the evolution of the macro-structural characteristics of a network is driven by concurrent forces operating at the micro-level (Powell and Grodal, 2005; Powell *et al.*, 2005). This idea recalls the sociological network approaches of Granovetter (1973) and Burt (1992), in which knowledge sharing and acquisition are related to the various structural properties of the individuals' positions (Foss, 2010; Fonti and Whitbred, 2011). This work fits into this strand of research.

Strategic networks show a variety of different network configurations such as strategic alliances, joint ventures, long-term agreements, industrial districts, clusters (Porter, 1998), franchising and other similar agreements or contracts (Antoldi *et al.*, 2011). Firms engage in cooperation not only to share the costs and risks of research activities, but also to obtain access to new markets and technologies, make use of complementary skills, and so on (Hagedoorn *et al.*, 2000; Kogut, 2000; Pika, 2002).

Inkpen and Tsang (2005) classified different kinds of networks according to two criteria: the nature of the agreement among the partners and the position of the latter along the entire value chain (Fig. 1).

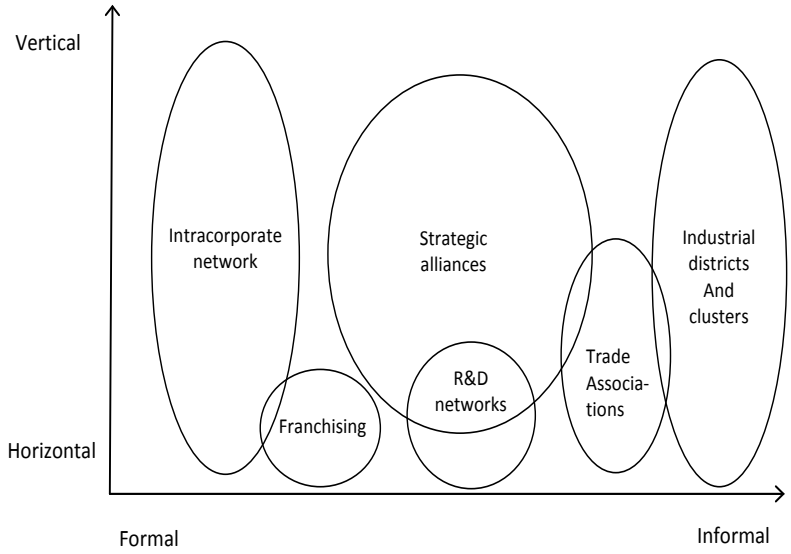
In this research strand, we focus on policy-supported innovation networks or, as Inkpen and Tsang (2005) call them, "R&D consortia". These are temporary project networks organized around a leader in order to answer to a public opportunity of financing.

A large strand of research has used policy-supported networks as a proxy for investigating network relationships and dynamics (Sedita, 2008; Belussi and Staber, 2011). Ample space has been devoted to the analysis of European policies on the Framework Programme (FP) that aims at promoting innovation networks (Protogerou *et al.*, 2013). The investigation touches on the evaluation of European and regional policies on innovation networks (Bellandi and Caloffi, 2010), with regard to the influence of public programs on R&D collaboration strategies among firms (Matt *et al.*, 2012). In the last few decades, European countries have made strong efforts to promote cooperative research and collaboration among firms in R&D, such as joint research ventures (Caloghirou *et al.*, 2004).

After this brief literature review, we remind that the purpose of this research is to focus on a specific type of strategic networks, the temporary innovation networks in order to investigate the relevance of the actors' position and their centrality in the innovation process. The study contributes to the wide strand of research on the importance of network competences (Ritter and Gemunden, 2003) and relational capabilities for

innovation in clusters (Hervas and Albors, 2009). We are aware, however, that this choice has some positive and negative aspects. This approach allows us to focus on firms external innovation dynamics, recognised as relevant aspects in this business (IRPET, 2012; Casprini *et al.*, 2014). On the other hand, it focuses only on temporary formal innovation networks that are only the tip of the iceberg of the firms' external innovation dynamics (Hagedoorn *et al.*, 2006; Sedita, 2008).

Fig: 1: A typology of network types



Source: our re-elaboration from Inkpen and Tsang (2005, p. 149).

2.2 High technology applied to cultural goods in Tuscany

HTCG is a newly emerging business for firms in various industries, such as ICT, geology, chemistry, biology, engineering and physics-optoelectronics (Casprini *et al.*, 2014).

This is particularly true for Florence and Tuscany where a technological cluster has formed during time, specialized in the restoration and enhancement of their rich and internationally-renowned cultural heritage (Lazzeretti *et al.*, 2011; Lazzeretti and Capone, 2009).

The local cluster has started to develop in the early 2000s, thanks to policies supporting inter-organizational networks in HTCG. The cluster has developed rapidly and, after about ten years, has reached a total of more than 400 associated actors: firms, research centres and universities (Salimbeni, 2012). In 2011, the Tuscany Region recognized the relevance of this sector and founded the Technological District in Cultural Goods (TDCG) in order to support local R&D activities and improve local governance.

Recent research has also been devoted to the study of innovation in HTCG. Casprini *et al.* (2014) analysed business modules in HTCG, surveying 30 firms in Tuscany. Lazzeretti (2012) and IRPET (2012) were

among the first to analyse this business, pointing out its relevance in Tuscany from the innovation perspective. Lazzeretti and Capone (2015) pointed out that HCTG is a particularly interesting sector, as it develops transversal innovations related to several scientific domains.

It could be useful then to describe some technological innovations in this business. A first example is the development of a laser for the restoration of cultural heritage, built in a policy-supported R&D project between a local large multinational firm with *expertise* in laser for biomed - the National Research Centre (CNR), with high skills in optoelectronics and physics - and local cultural organizations (Salimbeni *et al.*, 2002). A second important innovation is the development of chemical nanotechnologies and gels for the conservation and restoration of cultural heritage, developed at the University of Florence by a network of researchers from the Department of Chemistry (Lazzeretti and Capone, 2015).

A last important innovation that had a relevant impact is the 3D visualization and rendering *software* and digitization of cultural heritage and, in particular, the digitalization of the work of arts at the Uffizi (Uffizi Touch™) that has a significant impact at firms' level (Centrica, 2013).

HTCG is in fact an emergent business that has recently received an increasing interest from innovation scholars and even from the Italian authorities to improve the competitiveness of local firms (Bifulco, 2009; Di Pietro *et al.*, 2014).

HTCG is particularly relevant to innovation studies as it is a high-technology and complex sector, based on transversality and cross-fertilization processes (Cooke, 2012; Staber, 2009).

In this context, it can be useful to investigate who are the main actors operating in this business and to identify most important strategic networks, proposing a first analysis of the phenomenon.

3. Research design

The present study represents the last stage of a long-term research project focusing on the technological cluster for cultural goods in Florence and Tuscany. The units of analysis are the R&D projects for innovation in the field of safeguard and enhancement of cultural heritage, developed in the Region.

The R&D projects were selected through a survey submitted by e-mail to the main regional research organizations specialized in this field. The Institute of Applied Physics of the National Council for Research (IFAC-CNR) - identified as the key player in the development of laser technologies for restoration (Lazzeretti *et al.*, 2011) - was taken as the starting actor and the sample was expanded through snowball sampling (Goodman 1961), like in other contributions for reconstructing local networks (Sammara *et al.*, 2006). The other actors identified are the organizations that have shared the proposal presented by IFAC-CNR for the regional Technology District for Cultural Goods[3], that also coordinated the projects developed

[3] The proposal has been first presented at the conference *Europa 2020: Innovazione nel Mediterraneo edilizia eco-sostenibile e distretti dei patrimoni culturali. Governance, esperienze e progetti*, Florence, 26-28th January 2011

over the last fifteen years in the field of cultural goods in Tuscany. We have interviewed all the (public) research centres and universities involved in HTCG operating in Tuscany. The interviewed group included 15 actors, among which 6 research centres affiliated to national institutes of research and 9 university departments or faculties.

As a result, 42 R&D projects were collected in the database. They were funded through regional, national and international calls covering a time span of more than fifteen years (1995-2012) and involving Triple Helix actors like firms, small and medium-sized enterprises (SMEs) and large firms, research centres and universities.

The range of technological applications represented in the projects is rather broad and encompasses technologies for the preservation, diagnostics, restoration, documentation, fruition and communication of cultural artefacts. In addition to laser technologies, thus, the sectors of nanotechnologies, chemistry, nuclear physics and ICTs are also represented in the projects.

Face-to-face interviews with the leading actors were conducted in the first semester of 2011, a first online questionnaire was administered at the end of 2012 and a final control was done in 2013 in order to collect information on all the projects implemented at a regional, national and international level with the participation of Tuscan firms.

In order to analyse network dynamics between the actors, the database was organized so as to apply SNA (Wasserman e Faust, 1994) with the objective of highlighting the inter-organizational relationships activated by the co-participation in R&D projects (Sciarelli and Tani, 2014). For each actor, in addition to the number of projects to which it participated, other attributes have been investigated for elaborating descriptive statistics: financial contributions received; location; type (research centre, firm, university, institution); area of specialization, etc. Tab. 1 summarizes the main information about the 42 R&D projects.

Tab. 1: The 42 analysed projects in cultural goods in Tuscany (1995-2012)

Title*	Acronym	Call	Funding organization	Coordinator	Period	Nr. partner	Overall costs (M€)
Tools and Expertise for 3D Collection Formation	3DCOFORM	IST FP7	European Community	University of Brighton, UK	2008-12	19	11
Laser analysis of precious metals and ambers	ALMA	POR CREO 2009 Action 1.5	Tuscany Region	Marwan Technology Srl	2009-2011	6	0.7
Advanced Search Services and Enhanced Technological Solutions for the European Digital Library	ASSETS	ICT-PSP call identifier CIP-ICT PSP 2009-3	European Community	Engineering/ Informatics	2010-12	24	5.3
AUTHENTICO	AUTHENTICO	FP6	European Community	European Jewellery Technology Network	2007-09	10	1.1

(Salimbeni, 2011). It has been then submitted to the Tuscany Region, which took it into consideration along the process that led to the definition of the TDCG.

Title*	Acronym	Call	Funding organization	Coordinator	Period	Nr. partner	Overall costs (M€)
Development and application of mineralogical and petrographic survey methodologies for the study of archaeological objects	COFIN2000	PRIN 2000	MURST	Department of Earth Science, University of Siena	2000-03	5	0.7
Materials derived from the ancient science of geo-materials: transferring knowledge base of geosciences in the study of glass and metals	COFIN2004	PRIN 2004	MURST	Department of Earth Science – University of Pavia	2004-07	5	0.3
Preventive Conservation of Contemporary Art	COPAC	P.A.R. FAS 2007-2013 –1.1.a.3	Tuscany Region	INSTM	2011-13	3	1.6
Artworks Conservation by Laser	COST Action G7	COST Action G7	European Community	FORTH-IESL (2000-2006)	2000-06	35	0.6
Advanced On-Site Restoration Laboratory for European Antique Heritage Restoration	CULTURA 2000.2003	Framework Programme Culture 2000	European Community	National Museum of History and Archaeology (Constanta)	2003-04	5	0.4
Saving sacred relics of European Medieval Cultural Heritage	CULTURA 2000.2005	Framework Programme Culture 2000	European Community	National Institute of Research and Development for Optoelectronics	2005-06	5	0.37
Cultural Heritage & Tourism Store for the management of value-added application services	CUSTOM	POR CREO FESR 2007/2013 –R&S	Tuscany Region	Telecom Italia SpA	2010-12	5	2
Developments in ANalytical Nuclear TEchniques	DANTE	Commission INFN	National Institute of Nuclear Physics (INFN)	INFN Firenze	2006-08	3	0.26
DELOS: a Network of Excellence on Digital Libraries	DELOS	Network Of Excellence ICT FP6	European Community	ISTI-CNR	2004-07	47	15.3
Exterior beams in outdoors	FARE	Commission INFN	IFNF	INFN Firenze	2009-11	2	0.09
Monitoring accuracy and reproducibility in the analysis of Mass Spectrometry with Accelerators	MARASMA	Commission INFN	IFNF	INFN Firenze	2006-08	1	0.065
Application Methods for Studies of Art and Pollution	MASAI	Commission INFN	IFNF	INFN Firenze	2003-05	6	0.25
Multilingual/ Multimedia Access To Cultural Heritage	MultiMAtch	ICT-STREP FP6	European Community	ISTI-CNR	2006-08	10	4.3
Monitoring and diagnostics of frescoes in the Camposanto Monumentale of Pisa	MONDI	POR CREO IV – Action 1.1	Tuscany Region	CNR-ICCOM	2009-13	6	1.17
Optocantieri	OPTOCANTIERI	PRAI-ITT	Tuscany Region	IFAC-CNR	2002-04	23	0.5

Title*	Acronym	Call	Funding organization	Coordinator	Period	Nr. partner	Overall costs (M€)
Cultural Heritage Advanced Research Infrastructures: Synergy for a Multidisciplinary Approach to Conservation/ Restoration	CHARISMA	FP7, Research infrastructures INFRA -2008-1.1.1	European Community	University of Perugia	2009-12	23	9.6
Technological pole of the Sustainable City	POLIS	POR CREO – CALL 1.2	Tuscany Region	University of Florence, FRI	2011-2014	7	1
Strategy for the Preservation of plastic artefacts in museums collections	POPART	FP7-ENV-2007-1 – Grant. N 212218	European Community	CRCC – CNRS (France)	2008-12	12	2.9
Development of methods and systems of laser cleaning in the restoration of artefacts	PROGFIN	CNR "Cultural Goods" 1996-2001	CNR	IFAC-CNR	1996-99	1	0.23
Photoablation techniques in restoration	PROGSTRAT	Strategic Project CNR 1995	CNR	IFAC-CNR	1995	1	0.023
The Museum of Pure Form	PUREFORM	ICT – FP5	European Community	PERCRO – Scuola Superiore Sant'Anna	2001-04	9	1.92
Reduction of uncertainty in geological archaeometrical dating and environmental measurements	RIDAGMA	Commission INFN	IFNF	INFN Firenze	2009-11	4	0.28
Microwave eflectometry for the diagnostics of cultural goods	RIMIDIA	POR-FESR 2007 – 2013 Action 1. d	Tuscany Region	DET – University di Firenze	2010-12	7	0.20
Cleaning of the façade of the San Frediano Church in Pisa	RIS+ Cantiere	RIS+ Tuscany 2000-2001	Tuscany Region	RESTAURO ITALIA s.r.l.	2000	8	-
Nd: YAG Laser System for the restoration of metal artefacts	RIS+ Prototipo	RIS+ Tuscany 2000-2001	Tuscany Region	IFAC-CNR	2000	4	0.13
Techniques and laser systems for the restoration of cultural heritage	RRAT-1	RRAT-1 1997-2000	Tuscany Region	IFAC-CNR	1998	6	0.22
Laser systems for the restoration of paint layers and artefacts	RRAT-2	RRAT-2 1997-2000	Tuscany Region	CEO	1998	6	0.17
Development of chemical investigations applied to the preservation and restoration of works of arts	SICAMOR	PAR FAS – Action 1.1.a.3	Tuscany Region	DC-UNISI	2011-13	3	0.91
ST@RT	START	CIPE FUNDS	Tuscany Region	INOA-CNR	2008-10	12	3.6
Optoelectronic technologies for restoration sites	SUMUS	POR CREO FESR 2007-2013	Tuscany Region	Menci software S.r.l.	2009-11	4	0.46
Innovative technologies for the conservation and enhancement of cultural heritage	TECONBC	POR CREO FESR 2007-2013	Tuscany Region	CNR-ICVBC	2010-2012	7	2.5

* Our translation when necessary

Title*	Acronym	Call	Funding organization	Coordinator	Period	Nr. partner	Overall costs (M€)
The Virtual City	V-City	IST FP7	European Community	CS-SI (France)	2008-11	7	3.7
Virtual Heritage: High-Quality 3D Acquisition and Presentation	ViHAP3D	IST FP6	European Community	Max Plank MPII (Germany)	2002-05	6	2.4
VIsual Support to cultural heritage InTeractive access in Tuscany	VISITO Tuscany	POR-FESR 2007-2013	Tuscany Region	ISTI-CNR	2009-11	4	3.8
Virtual Museum Transnational Network	V-MusT.net	IST FP7	European Community	CNR	2011-15	20	5
The short life of the tannin	VAT	PAR FAS 2007-2013 Action 1.1.a.3	Tuscany Region	DCCI-UNIPI	2011-2013	3	0.38
Innovative techniques for the diagnosis and treatment of biodeteriogens in the artistic and archaeological fields	TDT BIOART	POR FESR 2007-2013 Action 1.1d	Tuscany Region	LABORATORI ARCHA SRL	2009-10	6	0.2
Advanced techniques for the understanding of matter and conservation of historic heritage	TEMART	POR-FES 2007-2013, Action 1.1d	Tuscany Region	IFAC-CNR	2010-12	13	3.2

Source: our elaboration

4. The analysed R&D projects

The selected projects cover a time frame of fifteen years (1995-2012) and registered a total investment of 89 M€, with some projects being still in progress and will be completed in the near future (Tab. 1). The projects are very heterogeneous in terms of financing institutions, budget requested and number of partners involved.

The R&D projects deal with restoration and enhancement of cultural heritage in regional, national and international calls. Twenty-nine of the 42 projects submitted were coordinated by actors located in Tuscany, which highlights the good organizational skills of regional actors.

As regards funding, 14 projects were financed by the European Community, while 19 were submitted to the Tuscany Region. A few others were submitted to specific organizations such as the Italian Research Council (CNR) (2) or the National Institute of Nuclear Physics (5).

The R&D projects result of different size and importance (Tab. 2). The largest group is composed by small projects under 0.5M€ and large projects over 2M€. Small projects have in average 4 partners, while large projects arrive up to 15 partners. Partners and funds are distributed heterogeneously, in fact while 20% of the partners involved in small projects collect only 4% of the total funds, 81% of the funds are financed in large projects involving 50% of the actors. The sample is therefore representative of a wide range of initiatives which converge toward the application of high technology for cultural goods, in its broadest sense.

Tab. 2: Summary of project funding ranges

Projects funding range	N. projects	Percentage of n. projects	Average n. of partners	Total funds (M€)	Percentage of funds
0.0-0.5 M€	16	39	4.3	4	4
0.5-1 M€	6	15	12.2	4	5
1-2 M€	6	15	6.7	9	10
>2 M€	13	32	15.7	73	81
Total	42	100	9.1	89	100

Source: our elaborations

5. The R&D policy-supported networks

In this section, the relationships among the actors set in motion by participating to the 42 projects financed are examined with the help of SNA (Wasserman and Faust, 1994; Scott, 2012). This section is organized as follows: section 5.1 presents some descriptive statistics concerning the actors involved in the projects (location, typology, budget, area of expertise, etc.); section 5.2 illustrates the relationships between the actors and reports some indexes on their centrality in the network; section 5.3 focuses on the graphical analysis of the networks.

5.1 The main characteristics of the networks

The 42 selected projects involve 267 actors for a total of 386 presences. At first, information of particular interest for our purposes is the localization of the actors (Tab. 3). Most actors are Italian, representing around 55% of the total. However, the network has an international dimension, as the European actors account for around the 45%. Within Italy, Tuscany, and specifically Florence, are the most relevant locations with more than 23% of actors located in Florence and 18% in Tuscany. The Pisa area also plays a particularly important role with 35 players and approximately 9% of the total.

Tab. 3: Distribution of actors by location

Localization	N. of actors	Percentage
Europe	174	45.1
Florence	91	23.6
Tuscany	70	18.1
Italy	45	11.7
Extra European countries	6	1.6
Total	386	100.0

Source: our elaboration

The analysis of the typology of actors (Tab. 4) confirms the high participation of research centres, universities and firms. Altogether, these three groups account for over 75% of all actors, with an important role

of the research centres (about 31% of total), followed by firms (17.6%), which include both SMEs and large companies. In absolute terms, there are 68 SMEs, while large firms are 12. It is worth noting the weight of local authorities with approximately 15% of presence, due to the involvement of actors who provide artistic and cultural heritage for the tests and trials (museums, cultural organizations, etc.).

Tab. 4: Distribution of actors by typology

Typology	N. of actors	Percentage
Research centre	121	31.3
University	108	28.0
SME	68	17.6
Public body	57	14.8
Service centre	12	3.1
Large firm	12	3.1
Academy	6	1.6
Others	2	0.5
Total	386	100.0

Source: our elaboration

Regarding the actors' competences (Tab. 5), it is necessary to remember that the actors have been classified on the basis of their contribution to the project, instead of their generic sector of activity.

Tab. 5: Distribution of actors by competence area

Competences	Number of actors	Percentage
ICT	86	22.3
Conservation	52	13.5
Optoelectronics	37	9.6
3D visualization	30	7.8
Physics	28	7.3
Restoration	26	6.7
Chemistry	23	6.0
Other	17	4.4
Museums	16	4.1
Environment	13	3.4
Diagnostics	13	3.4
Material sciences	9	2.3
Firms services	8	2.1
Research cooperation	7	1.8
Publishing	4	1.0
Media	4	1.0
Optics	4	1.0
Art and design	3	0.8
Telecommunication	3	0.8
Electronics	2	0.5
Total	386	100.0

Source: our elaboration

ICT for cultural heritage is the area that records the highest participation, with more than 86 subjects, representing the 22.3% of the total. This is followed by the area of Conservation with over 42 actors, about 13.5%. Optoelectronics settles down to 37 players, representing about 10% of participants. As many projects are devoted specifically to 3D visualization, this was subdivided from the generic area of ICT. 3D visualization records alone 30 actors (7.8%), while ICT together with 3D visualization accounts for more than 30% of the total. Other significant areas of *expertise* are Physics, with 28 players (7.3%), Restoration with 7.4% and Chemistry with 6%, followed by Museums with about 4%.

5.2 The analysis of relationship dynamics

In this section, the relationships set in motion by the actors participating in the 42 financed projects are examined with the help of SNA (Scott, 2012; Wasserman and Faust, 1994). This technique allows, in fact, to capture the network structure, the position held by each actor and the governance relations through the analysis of the global network, which is represented using graphs (Scott, 2012).

The first set of information represents the actors' rate of participation (Tab. 6), which clearly shows the importance of the Institute of Applied Physics (IFAC-CNR), which has been involved in the partnership of over 17 projects. The second actor with a high participation is the Institute of Information Science and Technology of the CNR (ISTI-CNR), which participates in over 10 projects. Particularly interesting are also the values of other organizations, such as the Opificio Pietre Dure (OPD), INFN (Florence), El.En. SPA (a big firm specialized in life sciences), the Department of Environmental Sciences of the University of Siena (DST-UNISI) and the Institute of Conversation and Enhancement of Cultural Heritage of the CNR (CNR-ICVBC). Finally, the Media Integration and Communication Centre of the University of Florence (UNIFI-MICC) and the Institute of Chemistry of Organic-metallic compounds of the CNR (CNR-ICCOM) participated in 4 projects. Regarding large firms, after El.El, there is the important role of Fratelli Alinari, the oldest firm in photography in the world located in Florence, Colorobbia for its role in nanotechnologies applied to cultural goods and Telecom for 3D rendering.

Since 213 of the 267 actors (80% of the total) participated in only one project, we can infer a small cohesion, signalling the likelihood that the central unit that carried out the innovation activities was composed of an extremely restricted number of actors (54).

One of the key concepts in SNA is centrality, aimed at identifying the most significant actors from different points of view. The first index is the degree of centrality, which corresponds to the number of direct connections a single actor has built. This is the easiest and most intuitive way to define the position of a node in a network. Tab. 6 shows the values registered by the most central actors.

The core actors are ISTI-CNR, IFAC-CNR and the UNIFI-MICC. These are the true gatekeepers of the network, who have the largest number of contacts with other participants. The fact that these central nodes are

research centres is coherent with both the nature of the projects analysed, aimed at R&D, and with the need of these actors to activate external resources. At a lower degree of centrality there are more heterogeneous actors, among others, the OPD, ICVBC-CNR and other international organizations.

A second index is the betweenness centrality. It quantifies the number of times a node acts as a bridge along the shortest path between two other nodes, which denotes the importance attached to a certain actor in a relationship network, in terms of its role as a go-between contact with other subjects. In this respect, ISTI-CNR, IFAC-CNR and MICC-UNIFI maintain their central positions together with other important research centres and the OPD. We will return to this later in the next section.

Tab. 6: Actors per participations, degree centrality and betweenness (main 20 actors)

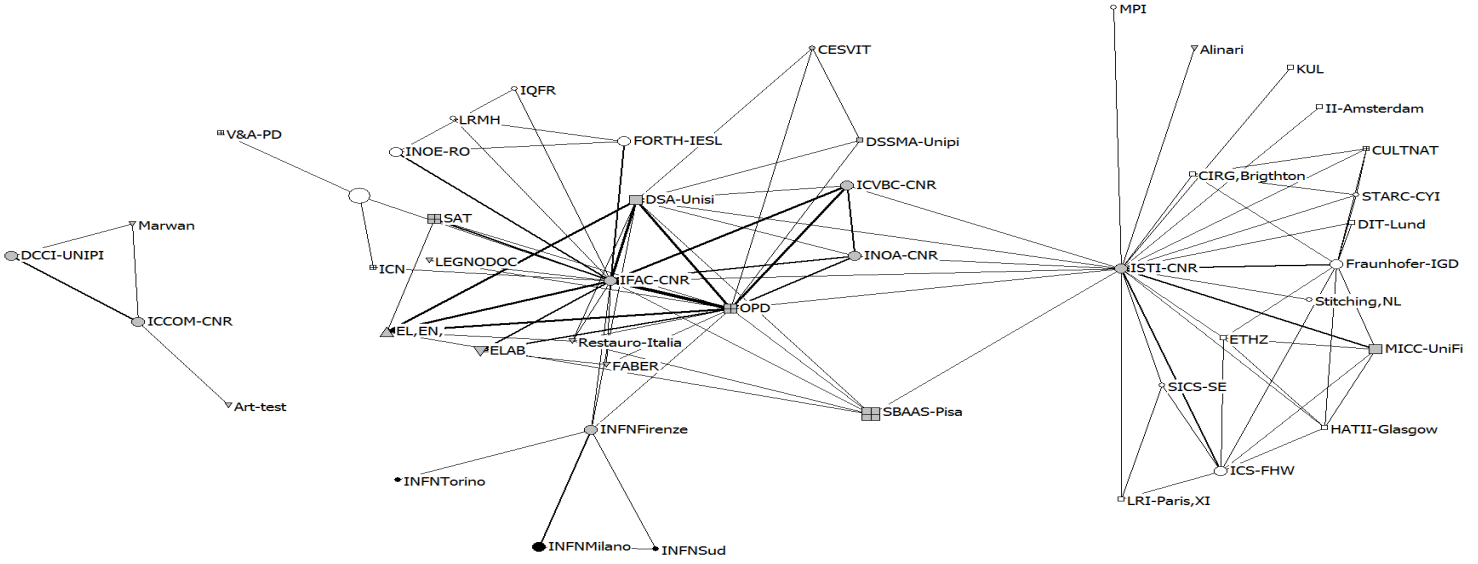
Actors	Projects	Degree	Betweenness
ISTI-CNR	10	30	271.40
IFAC-CNR	17	27	183.26
MICC-UNIFi	4	24	160.40
OPD	11	24	178.09
ICVBC-CNR	6	22	287.45
LC2RMF–CNRS	3	19	60.95
Fraunhofer-IGD	3	17	7.58
ICS-FHW	3	17	9.79
INOA-CNR	3	17	19.26
DSA-UNISI	6	16	23.96
ETHZ	3	16	4.82
HATII-Glasgow	3	16	4.82
CULTNAT	3	15	12.00
EL.EN.	5	15	19.25
APRE	3	14	31.31
DIT-Lund	3	14	4.18
INFN Firenze	5	14	199.53
CIRG Brigthton	3	13	1.13
STARC-CYI	3	13	1.13
V&A-PD	3	13	10.06

Source: our elaboration

5.3. Graphic representation of the network relationships

As mentioned, the network can be represented by a graph, i.e. a set of points corresponding to the actors (called nodes) connected by lines corresponding to the relations that bind them (Scott, 2012). The graph, in summary, is the two-dimensional representation of a network of inter-links between a population of actors. It is then possible to analyse both the position of each actor in the topology of relationships, and the morphological characteristics of the relational network as a whole.

Fig.1: The technological network on cultural goods in Tuscany (c>2)



Legend of nodes: Grey nodes for actors localized in Florence and Tuscany, black nodes for the rest of Italy and white nodes for Europe. The different shapes show the typology: circle for research centres, square for universities, triangle for firms (arrow up large companies, arrow down SMEs), square with cross for institutions. The value expressed by "c" stands for the minimum number of projects each couple of actors share.

Source: our elaboration.

As the global network is too numerous to analyse graphically (due to the large number of nodes), Fig. 1 shows the network by considering a co-participation to at least two projects[4]. The thickness of the lines indicates the number of projects attended by two subjects, in other words the "thickness" of the relationships.

The most interesting result is the emergence of three different sub-networks. The first one in the middle of the graph relates to the themes of Optoelectronics and Restoration, with IFAC, OPD, El.En and DS-UNISI; the second one, on the right, operating on ICT and 3D imaging, with ISTI CNR, MICC-UNIFI; and finally the third one on the left, smaller and "isolated", relates to the Chemistry area with ICCOM-CNR and DCCI-UNIPI. The international actors are represented on the right side of Fig. 1 (white knots), while in the centre and the left are mainly the local actors (grey knots). Network 1 insists mainly on the city of Florence (grey knots), involving also local organizations and institutions; it has just a slight connection with some European actors (above in the graph, white knots). ISTI-CNR acts as a local gatekeeper between the two networks (in the right centre). Regarding the other actors of the network 1, the network of INFN emerges clearly. It links the INFN laboratories in Turin, Milan and South Italy to Florence by implementing projects related to the experimentation of new techniques of analysis of materials.

Regarding the typology of actors, Network 1 is highly heterogeneous involving companies, organizations and institutions. Network 2 (on the right) is mainly composed of international actors as research centres and universities. Network 3 (on the left) on Chemistry includes two research centres and two firms. These differences are mainly due to the orientation towards or away from end-users.

Regarding the actors' competences, Fig. 2 shows that Network 2 is focused primarily on ICT and 3D visualization of cultural heritage (Circle-in-box and square nodes) and there are just few actors specialized in Conservation (Up triangle). The analysed projects, in fact, focus on industrial research without direct involvement of public institutions, such as museums (categories that are also excluded from EU funding).

Network 1 on Restoration is more diversified in terms of skills and includes subjects like Optoelectronics (Up and down triangle) and Physics (Down triangle). Network 3, as already highlighted, operates in Chemistry (Circle nodes).

It is possible, at this stage, to analyse the structure of the network by considering a higher level of co-participation, in order to detect how network dynamics change and the evolution of the key actors. A level of co-participation to 3 project permits to highlight the strategic network - composed by a small number of actors.

As reported in Fig. 3, the main network is divided into four separate components. In addition to the network of INFN, the previous three sub-networks emerge clearly: Network 1 localized mainly in Florence, ICT Network 2, more open to a European dimension, and Network 3 of Chemistry.

[4] This means that a couple of actors have participated together to at least two projects.

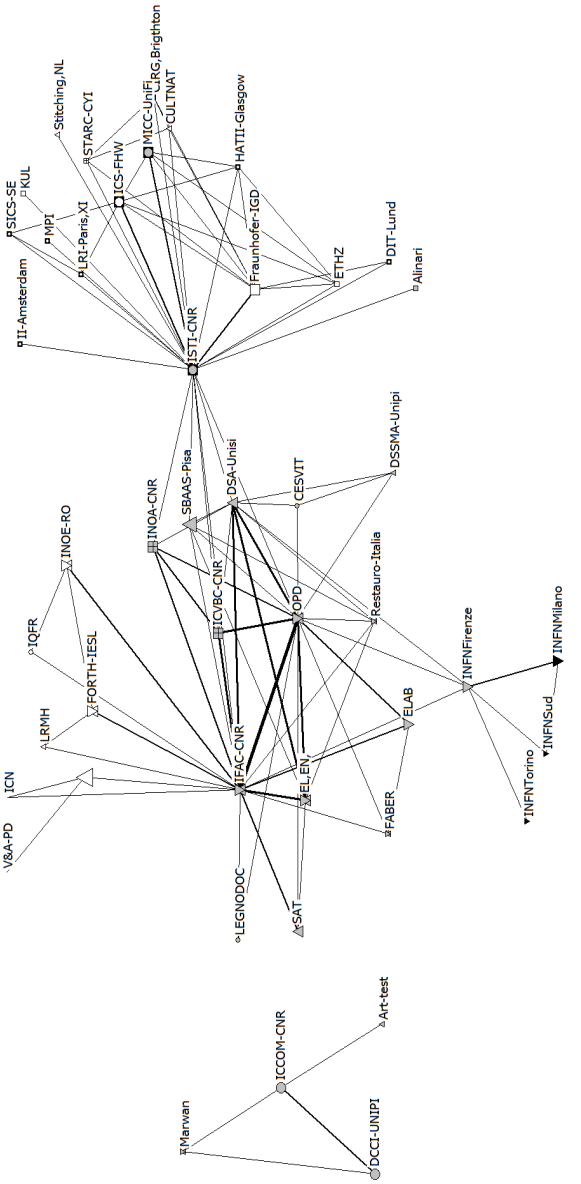


Fig. 2: The technological network on cultural goods in Tuscany by competences (c>2)

Legend of nodes: For nodes' colours see Figure 1.

Source: our elaboration.

The first and biggest sub-network includes a large part of the Florentine actors, along with a node located in Siena (DST-UNISI) and two international players (INOE-Romania and IESL-FORTH). In addition to the previously identified ones (IFAC-CNR, OPD and El.En), the main actors of this network are the ICVBC-CNR, the Institute of Optics of CNR (INOA-CNR), the Laboratory of Archaeology of the Superintendence of Cultural Goods for Pisa, Livorno and Massa Carrara (SAT) and the firm ELab, spin-off of the CNR. Most of them, as indicated, are universities and research centres.

Network 2 on ICT for digitalization and imaging of cultural heritage is centred on ISTI-CNR in Pisa and UNIFI-MICC in Florence, notwithstanding its international openness as evidenced by the presence of the Fraunhofer Institut für Graphische Datenverarbeitung (Fraunhofer-IGD, Germany) and the Institute of Computer Sciences of the Foundation for the Hellenic World (FHW-ICS) in Greece, both specialized in computer sciences and visual computing.

Network 3 is specialized in Chemistry and composed by DCCI-UNIPI and ICCOM-CNR. It is also located in Tuscany and, specifically, in the cities of Pisa and Florence. This network is connected to other actors through links with local institutions like the OPD and the Superintendence.

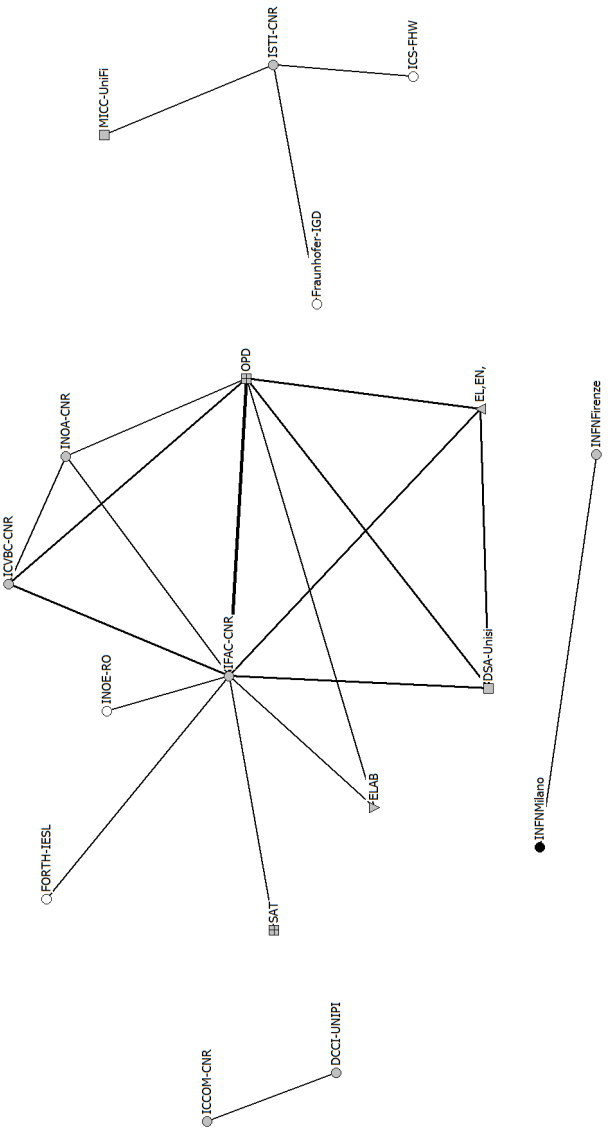


Fig. 3: The technological network on cultural goods ($c \geq 3$)

Legend: see Fig. 1.

Source: our elaboration

Finally, it is possible to represent in a graph the actors' betweenness centrality values, which are drawn from the size of the nodes (Fig. 4). The betweenness is based on the importance that an actor can have within a network as an "intermediary" between other actors. ISTI-CNR and CNR-IFAC are confirmed as leaders of the network. However, a significant presence of local actors serving as gatekeepers and connectors, such as ICVBC-CNR, OPD and UNIFI-MICC, emerges also quite clearly. A last actor, ICCOM-CNR, works as a "bridge" between Restoration and Chemistry actors.

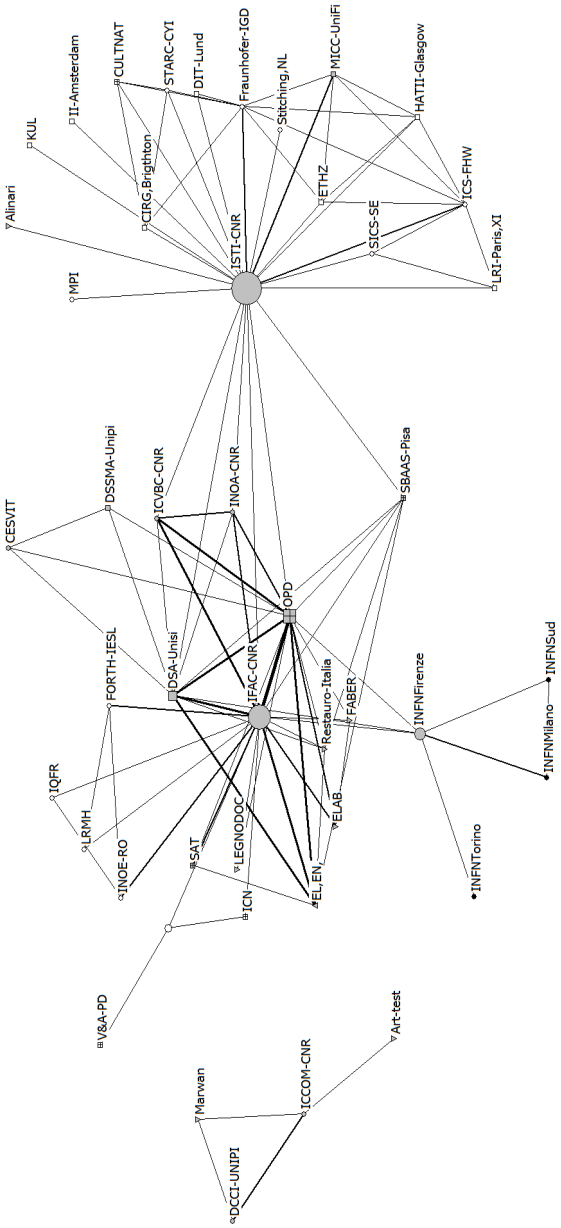


Fig. 4: The technological network on cultural goods in Tuscany ($c \geq 2$)

Legend: see Fig. 1; the nodes' dimension represents the betweenness of the actors (see Tab. 6).

Source: our elaboration.

6. Conclusions and managerial implications

The aim of this research was to investigate the relationship dynamics of networks for innovation in the business of HTCG in Tuscany. An ad hoc database has been created of 42 R&D projects in order to investigate the innovation networks along fifteen years.

Our study aimed to investigate the relevance of centrality and the actors' position in the networks. The study contributes to the wide research strand on the importance of network competences for innovation.

The results show that the business of HTCG is a complex one, in which inter-organizational relationships develop among actors of the Triple Helix, in public-private partnerships and industry-university relationships.

On the basis of this research, the business emerges as being in a development phase and presenting growingly relevant innovations. It is therefore necessary to underline the importance for managers of the relational competences for innovation and the relevance of (network) resources outside of firms' boundaries. HTCG emerges as a complex field, where a single company rarely owns all the resources and competences necessary to develop new products or services.

Cognitive ties among firms, research centres and universities are therefore particularly relevant, together with the ability of some actors to play the role of gatekeepers and benefit from the competences and expertise of research centres.

The architecture of relations is circular and denotes a sharing of knowledge among research centres, universities, businesses and institutions. Institutions in particular have a dual role: on one hand, they are the main interlocutors of the actors that engage in R&D (i.e. institutions such as museums and restoration organizations); on the other hand, they fuel the R&D process in economic terms by financing the projects (essentially the Tuscany Region and the EU).

Firms participate to the networks with two different roles. At first, they participate as end-users of the new technology, then they acquire the knowledge from research centres and universities, but companies may also participate as knowledge producers, playing the role of technological developers together with research centres and universities.

The birth and development of innovations is mainly due to the collaboration of all stakeholders of the Triple Helix: the research system (CNR, etc.), the industrial system (large and small firms) and institutions (Region, Superintendence, OPD). In fact, the close cooperation between public and private actors in the development of innovations is essential to complete the R&D projects. Firms usually offer a consolidated technology and the competences for producing a prototype, while Research centres and universities supervise the development of the new product (or services) and the adaptation of technological parameters of the new products for the restoration of cultural goods. The contribution of institutional actors is then added to this process, given that without funding the R&D projects would not even begin. Finally without good relations with local cultural organizations (museums, OPD, etc.), there would be no opportunities to test and validate it on cultural goods.

It is important then to point out the relevance of linkages among different scientific domains (for instance, between chemistry, physics, etc. and cultural heritage). In fact, innovations are usually developed firstly in a particular field (for instance, laser for biomed) and then through the processes of transversal innovation 'exported' as incremental innovation in another field (i.e. cultural heritage).

In the opinions of the interviewed actors, the factors associated with the local context (i.e. the cluster) are equally relevant. All the actors involved in the R&D projects noticed the presence in the local cluster of all the necessary factors for the development of innovations. In this context, the presence of a truly creative environment is highlighted, in the sense of a virtual space (the network), where relationships are able to trigger a multiplicity of connections among actors, such as to encourage the transformation of ideas into innovations, sometimes in different fields from those in which they were initially generated. This allows a dialogue between physicists, chemists and scientists of different types, and conservators and art historians. Moreover, the presence of a widespread endowment of artistic and cultural heritage in the region, together with the existence of a world-known institution in the restoration of cultural heritage (OPD) was another essential element for its innovations.

Notwithstanding the limits of this study, results are interesting and the investigation adds new knowledge on the relevance of firms' relational dynamics in the HTCG business. The strategic networks for innovation, in particular in the HTCG, even if of temporary nature, are crucial for firms to develop transversal innovations and create and sustain competitive advantages.

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Academic or professional position and contacts

Luciana Lazzeretti
Full Professor of Management
University of Florence and IFAC-CNR - Italy
e-mail: luciana.lazzeretti@unifi.it

Francesco Capone
Researcher of Management
University of Florence - Italy
e-mail: francesco.capone@unifi.it

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