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TECHNOLOGICAL INNOVATION IN CREATIVE CLUSTERS THE CASE OF LASER IN CONSERVATION OF ARTWORKS IN FLORENCE

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Abstract

The field of laser application to the restoration and cleaning of cultural assets is amongst the most thriving developments of recent times. Ablative laser technological systems are able to clean and protect inestimable works of art subject to atmospheric agents and degradation over time.

This new technology, which has been developing for the last forty year, is now available to restorers and has received a significant success all over Europe. An important contribution in the process of laser innovation has been carried out in Florence by local actors belonging to a creative cluster.

The objects of our analysis are the genesis of this innovation in this local Florentine context, and the relationships among the main actors who have contributed in it.

The study investigates how culture can play a part in the generation of ideas and innovations, and which are the creative environments that can favour it. In this context, the issue of laser technologies for the restoration of cultural heritage has been analysed as a case study in the various paths taken by the Creative Capacity of the Culture (CCC).

Track:. **M. Creative regions in a creative economy**

1. Introduction[1]

The debate on the relationship between culture and local development has been recently enriched with new suggestions, which mainly concern the issues of economic development, innovation and creativity (Power and Scott 2004; Wolfe and Gertler 2004).

The link between culture and economy is witnessing a new phase, in which the focus is on creativity rather than culture (OECD 2007). The attention has then shifted to innovative processes (Kebir and Crevoisier 2008; Potts et al. 2008), human capital (Florida 2002), and creative cities and industries (Landry 2000; Florida 2008).

Formerly, culture was basically considered as a good to preserve, and only afterwards as a possible gain, if properly advanced its itself and from an economic point of view (Towse 2002). At present the focal point of the debate is on a culture's capacity to produce knowledge, in other words on how both material and immaterial cultural resources can favour new ideas, and innovations (Lazzeretti 2009).

Our contribution enters upon the current debate analysing the case of laser technologies for restoration. The case is an interesting example of an innovation moved by a creative capacity of culture engendered by creative environments in art cities. Restoration is certainly an outstanding cultural sector, which has not been adequately studied so far, and where Italy, and Florence in particular, have developed a well-established tradition for a long time, gaining a position of international leadership (Salimbeni, Pini and Siano 2002; OECD 2005). Specifically, the field of laser innovation applied to the restoration and cleaning of cultural assets (for example, ablative laser technological systems) is one of the most thriving and successful technologies newly-available in Europe (Schreiner and Strlic 2006).

In addition, the present case study is meant to start investigating the cultural cluster of restoration as a creative cluster, and reconstruct, on the one hand the genesis of the innovation under study, and on the other the role of the strategic actors involved in the innovation process. Initially, the groundbreaking idea rose almost by chance (a serendipity case) in Venice – an art city as well – following an exceptional event, the flood of 1966. Twenty years later, it was developed and applied in Florence, where it found the breeding ground and the group of people able to implement it.

The actors who managed to develop and successfully apply the innovation were both economic (enterprises), non economic (University, CNR – the national research centre –, and preservation, protection and enhancement agencies), and institutional (local bodies and Tuscany Region). The development process of the innovation entailed a 'cross-fertilisation' among apparently-distant sectors (that is, medical diagnostics and cultural goods). It also profited from the location in an art city like Florence, a creative *milieu*, where high culture and high technology blend perfectly together.

The study is arranged as follows. After this introduction, Section 2 recalls the main characteristics of the paths resulting from the creative capacity of culture. The research scheme and the methodology of investigation are instead the object of Section 3.

In Section 4, the history of the innovation is examined from its genesis to its international diffusion, focusing on the Italian and Florentine experiences. In Section 5, the creative cluster of laser technologies for restoration is analysed throughout a series of research projects financed by the Tuscany Region exploring the relationships among the creative actors involved, with the help of the Social Network Analysis. In Section 6, some conclusive remarks and policy implications complete the study.

[1] The present research has benefited from the contribution of the Institute of Applied Physics IFAC-CNR on the project "Technology innovation and creative cluster in the conservation of artworks: the case of laser technology for restoration in Florence". Authors wish to thank in particular, prof. Masotti, dr. Giusti, dr. Salimbeni and dr. Siano for their helpful collaboration. However, any remaining errors are the sole responsibility of the authors.

2. The paths for the creative capacity of culture. A theoretical reference

In recent times, the relationship between culture and economy was subject to a change. The previous period, characterised by the so-called 'economic enhancement of culture', gave place to a dialectic phase, that can be identified in the 'cultural enhancement of economy' (Lazzeretti 2009).

In the first case, culture was basically seen as an asset and trusted to generate economic development and employment, just like any other factor of production. In the second case, instead, it is appreciated as a creative capacity, with a deeper concentration on its strategic role in innovation (Table 1).

INSERT TABLE 1 HERE

2.1. From the economic enhancement of culture to the cultural enhancement of economy

Within the economy of culture, a first important step was to move from the preservation to the economic enhancement of culture. A variety of scholars contributed to this multidisciplinary debate (Ginsburgh and Throsby 2006). Culture and economy were combined in a successful paradigm, which was first built in the US, later in Europe and, more recently also in transition and developing countries (Power and Scott 2004).

The initial purpose for this field of research was to prove that culture could be considered a factor of production, showing that it played an important role in the traditional cultural industries or in non-profit sectors. In this regard, an exemplary case is that of museums, non-profit institutions where an object of preservation can turn into the target of various forms of economic enhancement.

At that time, however, some idiosyncratic resources took up a strategic value, and concurrently cultural districts and clusters, with their different connotations, became the sign of an emerging phenomenon, the power of culture to guide economic development.

Some American scholars defined the cultural district as a 'well-recognised, labelled, mixed-use area of a city in which a high concentration of cultural facilities serves as the anchor of attraction' for other activities (Frost-Kumpf 1998: 29).

Some others worked out taxonomies meant to differentiate cultural districts from institutional, industrial, urban and museum districts (Santagata 2002); others drew attention to their role in territorial marketing, or pointed out the significance of their resources (Kebir and Crevoiser 2008); and still others studied the cultural districts in city of arts (Scott 2000; Lazzeretti 2008).

A further step in this stream of studies was to start considering culture as a source of innovation capable of generating new ideas and improvements, rejuvenating mature sectors or creating new industries. Some analyses were so much concerned with the role of creativity that their focus gradually shifted from cultural districts to the creative districts (OECD 2005) in the US, Europe and, finally, Asia (Scott 2005).

In parallel to the rise of concern for creative districts and industries, a renewed attention grew for the concept of 'creative city', a notion directly related with those of 'cultural city in the new millennium' (Hubbard 2006) and 'city of knowledge'. This revised concept was soon related to the creative industries (Hall 2000), and later to the creative class (Florida 2002). Florida's contributions gave rise to a particularly intense debate on this issue (Glaeser 2005; Storper and Scott 2009; KEA, 2009), and generated a very large quantity of empirical research (Boschma and Fritsch 2009; De Propris et al. 2009). On this point, the attention has recently shifted to an entrepreneurial approach that links creativity, new firms' formation, entrepreneurship (Lee, Florida and Zoltan 2004) and urban regeneration (OECD 2007).

In this context, this work should contribute to study the Creative Capacity of Culture (CCC) in the cultural clusters of art cities. By creative capacity of culture, is intended the ability to rejuvenate places, sectors or professions, and to generate ideas and innovations through processes of cross-fertilisation and serendipity. It involves searching new and different relationships, and preferably

the 'unusual' relatedness which is at the basis of the innovation process. The CCC is founded on a multifaceted idea of proximity, which is diversified not only on a geographical basis, but also cognitively (Boschma 2005).[2] The main objective becomes the search for 'relatedness', which constitutes the setting up of development paths for CCC.

2.2. The path for the creative capacity of culture

According to this perspective, four development paths are identified (Table 2), which wind between renewing and novelty, and are differently associated to the main typologies of innovation (rejuvenation, incremental innovation, radical innovation).

INSERT TABLE 2 HERE

1) *Urban renewal* was extensively explored by urban planners and then applied to initiatives of place-marketing and 'experience economy' (Pine and Gilmore 1999). An OECD report (2007), which was specifically devoted to this issue, recognised three main urban regeneration strategies:

- *City branding*. Place branding tries to apply the same methodology employed in product marketing to geographical locations, and to create and nurture the narratives that give meanings to a place (Julier 2005); it underlines its core benefits, and style culture.
- *Physical renovation and flagship developments.* Physical renovation, such as flagship city centre development, was conceived to bring branding images into reality by giving them a material form. According to this strategy a primary role is taken up by architects who are asked to furnish places with a new image and a new symbolic value: an exemplary case is that of the Bilbao Guggenheim Museum (Plaza 2006). An example of flagship development can be drawn from the 'waterfront city promotion' (Baltimora model).
- *Culture-led and driven strategies*. They regard the organisation of exhibits and events. Contemporary art museums are in this respect of particular importance in attracting mass tourism and entertainment (Griffiths 1995); also, international events, such as the Olympic Games and the World Expos, represent a chance of great consequence for urban regeneration, and for the reactivation of other economic *filières*. The Quarter Museum in Vienna constitutes a good example of this strategy (Mommas 2004).

2) *Economic renewal*. This path is not as well systematised, but no less important than that of 'urban' renewal. It pertains to the idea that culture can rejuvenate not only places, but also products, professions and sectors that are mature or declining. It can be achieved covering the following paths:

- *Industry regeneration*. A first case deserving mention is design that, from many viewpoints, may well represent a new cross-sector technology. Design can be successfully combined with the new ICTs, and its planning ability improved owing to the simulation of a product's virtual progress report, or it can gather new materials for the implementation of new products, as is the case for the shipbuilding industry.
- *Profession rejuvenation*. Even professions can be rejuvenated and find a resurgence if revitalised by new technology and creativity. An emblematic case is the high-tech artistic craft of the Florentine restorers, who work at a high specialisation level and, because of their localisation in the historical centre of the city, are considered at the same time a creative class, a creative firm and a source of urban regeneration.[3]

[2] Cognitive proximity can be found, for instance, in temporary networks of artists who come in contact for the organisation of cultural events (projects, exhibits and festivals) or, on a virtual level, in episystemic communities like the Open Source software.

[3] In fact, at first the artisan worker was associated with the traditional cultural firm, therefore it was merely seen as an *actor* in the cluster of art restoration whose activity contributed to the enhancement of a territorial resource, art. Instead, the same artisan firm can also be regarded as a cultural *resource* for the urban neighbourhood it occupies, because it

3) *Cross-fertilisation*. A third path is specifically associated with novelty rather than with regeneration. Jacobs (1961) had already stressed the importance for innovation of cross-fertilisation of ideas among industries, as well as among economic actors, and the wider community. The central points to consider are the 'relatedness' and the ability to look for and build new relationships. Even this kind of path was not sufficiently codified, so only a few examples drawn from our past researches can be described. Therefore, there appears to be the following cases for cross-fertilisation:

- *Inside a cultural cluster/district*. It can arise with regard to different professional abilities (specialisations) within a same productive *filière* or a same cluster/district; relatedness is based essentially on social and physical proximity (see the cluster of art restoration).
- *Among 'related' cultural clusters/sectors*. Another relevant example is given by relatedness among cultural clusters in the same city. The case might be that of institutional actors who belong to different clusters, so that they work as 'connection knots'. This certainly occurs in the clusters of fashion, museum and music in art cities. Besides, it is possible to have cluster-to-cluster relationships outside the city, relating a same kind of actors from different places, and even from different countries, like in the case of the relationships entertained by Florentine and Chinese restorers.
- *Among 'unrelated' clusters/sectors*. In the case of a multifaceted city, sectors which are apparently uncorrelated can have an opportunity of exchange just because of co-localisation. An example is given by the case under study, that is the cross-fertilisation between the biomedical and medical diagnostics sector and the sector of cultural assets, again in the city of Florence. The presence in the same territory of institutes of applied physics and institutions for preservation purposes, and clearly also that of a considerable art heritage, was probably at the origin of the implementation of laser technologies of optometry for cleaning stone materials (Salimbeni, Pini and Siano 2002).
- *Across time*. The last typology is a kind of cross-fertilisation which finds its roots in the legacy of tacit knowledge about the old and the new, the first and the second modernity: the rebirth of a *creative district*. This is the case, for instance, of BHM jewellery, a classical Marshallian manufacturing district which has presently been revived as an urban cluster founded on design, marketing and the new and distinct ethnic community of Indians, who brought about a whole set of relationships, especially at international level (De Propris and Wei 2009).

4) *Serendipity*. The last path is very different from the others and is quite hard to trace. Usually, the term 'serendipity' is described as the capacity of discovering pleasing or valuable things by chance. In this case, the CCC has to do with the discovery of an unusual correlation that becomes the basis for an innovative idea, which might be associated with new uses for a product, diversification, or technological correlations.

a) *New uses*. Coke, for example, was originally invented as a medicament and only later used as a soft drink; nonetheless, its formula is still a secret, just like that of any other medicament.
b) *Multiplicity of interests*. Diversity may also have a positive role, which makes sense with the lesson by Pasteur when he links his original idea of 'protection by inoculation with germs of weakened virulence' to his array of interests and his ability to make associations.

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helps revitalising that special place. Another noteworthy fact was that most of Florence restoration workers employ sophisticated technologies and have a high professional qualification, acquired either in the workshop or by attending high-training courses in local centres (such as the Workshop for Hard Stones, Opificio delle Pietre Dure). This is a case in which art, culture and technology intermingled and gave new impulse to an old profession, as well as to the Florentine central neighbourhoods in which the workshops are located, whose atmosphere was certainly enlivened (Lazzeretti 2003).

c) *Technological correlations*. The laser-cleaning technologies in art conservation are emblematic. They were discovered by chance while using laser to make a holographic archive of statues and monuments (Asmus, Murphy and Munk 1973). Another example is that of the metal-detector technology in airports: it was conceived by a jewellery firm and implemented for the selection process of metallic alloys to weight gold carats.

3. Research scheme and methodology

The object of the analysis is the restoration sector, which has been one of our favoured fields for investigating the relationship between culture and economy, and particularly that phase described as 'cultural enhancement of economy'. The purpose was to answer the following research questions: is the cultural cluster of art restoration – composed as it is by economic, non-economic and institutional actors – also a creative cluster able to generate changes and new products? And likewise: is Florence, city of art and culture, also a creative environment that can favour and advance the birth of ideas and innovations?

The interest for the analysis emerged at the time of the restoration of the Gates of Paradise by Ghiberti, which was carried out using the laser technology by a set of strategic actors from the Florentine and Tuscan setting. This fact led us to reconstruct the history of the laser innovation, specifically referring to what was going on, and also analyse the relational dynamics among that group of actors by examining the main funded projects.

The on-field analysis was achieved by using two different methodologies for collecting information. In the first stage, we conducted some in-depth interviews (Yin 2003) with privileged interlocutors, in terms of their role in the development of laser technologies for restoration. The interviews were made following the so-called 'snowball' method (Goodman 1961), which implies that the first person questioned is asked to supply the names of other subjects who also played a key role in the process, then the following person is asked the same question, and so on. This procedure was accomplished with the interviews of the main actors recommended by this way, who were in order: dr. Renzo Salimbeni (Director) and dr. Salvatore Siano (Research) of the IFAC-CNR; prof. Leonardo Masotti (founder and President of the scientific committee of El.En., a group that manufactures and distributes high-tech laser systems); dr. Annamaria Giusti (Director of the Sector for the Restoration of Stones, Bronzes and Ancient Weapons of the Workshop for Hard Stone – Opificio delle Pietre Dure, OPD); the building surveyor Paolo Bianchini of the Duomo Museum and dr. Beatrice Paolozzi Strozzi, Director of the Bargello Museum.

This first stage evidenced that the laser technology had been the result of a collaboration among different actors, motivated by a common planning activity. Consequently, in the second stage, an analysis of the projects was carried out. An *ad hoc* database was collected with the information provided by IFAC-CNR, an institution that had participated to almost all the projects and coordinated half of them.

Through this course of action, twelve projects were selected, covering a time frame of nearly fifteen years (1995-2009). The aim of processing the information so gathered was two-fold, since it helped to:

a) show the evolution of laser technologies applied to the sector of restoration, from its birth up to its recent developments, and bring to light the distinguishing factors at work;

b) go into the role of the key actors in the innovative process, and understand how the (human, technical, scientific, financial and relational) resources of the hypothetical creative cluster were set in motion.

In order to find the answer sought with the first aim of our study, for each project some general information were worked out (such as, their title, funding body, year, coordinator, number of partners, and so on) and some detailed information (role of the project, key elements, results) that were likely to explain the individual's effective contribution to the innovation development.

In order to respond to the second aim, instead, the database was arranged in a workable form for the application of the Social Network Analysis (Freeman 1979; Wasserman and Faust 1994), with the purpose of evincing the inter-subjects relationships deriving from the common participation to the projects.

4. The genesis of innovation and the experience of Tuscany

The application of laser for the restoration of cultural property was started off in the Seventies, with the works of John Asmus (Asmus, Murphy and Munk 1973), who first tested the potentialities of laser in cleaning a column in the Church of St. Gregory in Venice. Asmus realised that the ruby laser technique, usually applied to holographic processes, could also be efficacious for cleaning the dome's columns.

This 'accidental' discovery led Asmus to develop a series of tests on several materials, which he undertook in between 1972 and 1974. Once the technological potential of laser was verified, Asmus and his disciples embarked in a long experimental stage to back up the feasibility of this new practice for restoring cultural assets.

The importance and high potential of this technology was soon understood all over Europe, and over the subsequent years the countries with the greatest cultural endowments started to plan and implement activities aimed at developing the use of laser (Salimbeni, Pini and Siano 2002). However, it was not before the mid-Nineties (1994), with the approval of two European projects financed within the IV and V Framework Programmes,[4] that it was possible to implement and start the serial production of the first neodymium laser, which used the optic fiber to transport radiation to the light-emitting handpiece (Vergès-Belmin et al. 2003). In 1995, the first conference on *Lasers in Conservation of Artworks* (*LACONA*) was held in Crete. Since then the international community, made up of physicists specialised in restoration of cultural heritage, restorers (the real end-users) and developer enterprises, regularly meet every two years.

In Europe, many initiatives to develop laser-technology testing were undertaken, with several of them benefitting from the funding received through European projects[5].

However, although there has been ample experimentation to appreciate the impact – in terms of both its advantages and disadvantages – of using lasers in the preservation of cultural heritage, by the late Nineties, in Europe, a well-developed laser system for restoration fully accredited from restorers and conservators was still nonexistent.

In this situation, Tuscany reveals to have been the context where the greatest persistence was shown to test the use of laser for preserving and restoring cultural and art goods.

This undertaking was made by a public body, the Opificio delle Pietre Dure (OPD), a centre of excellence in restoration headquartered in Florence, that made a first attempt at a local firm, already in 1979, to verify the potentialities of the CO_2 laser technology, using a fixed system. The result of the test was not encouraging, because the laser was over-powerful and the marble would absorb too heat. However, in spite of the failure, this first testing gave the opportunity to make both OPD and the local community more aware on the use of laser.

About ten years later, in 1992, OPD established a collaboration with Institute of Applied Phisics[6] which was at first addressed at the cleaning of repaint, and later extended to the cleaning of

[4] The two projects were Brite-Euram LAMA, 'LAser MAnuporteable for stone conservation', ended in 1996, and Eureka-Eurocare RESTOR, ended in 2001.

[5] The first European projects gave a substantial financial contribution to laser application for marble and stone (LAMA, LASERART, RESTORE); soon after, other funded projects were addressed at the clearing of paper and vellum (LACLEPA, PARELA, PAPERTECH); later on, it was the turn of painting cleaning, which was the object of a laser-system programme with two projects (ENV2C and the more recent INART); several projects were also financed for the application of laser to diagnostics, and holographic records (LASERACT, HISTO-CLEAN, INTAS, as well as the latest PROMET and MULTIENCODE).

stone material. This experience encouraged OPD to deem feasible the design of a more proper device, and IFAC, having specific competencies in laser technology, suggested that the ideal implementer of such a programme could be El.En., a firm also located in Florence.

To this purpose, the project, called SMART CLEAN, got off the ground (Margheri et al. 2000) and developed a new laser system, the Nd:YAG, which obviously required a preliminary analysis of effects on different materials. The partnership of the El.En. group in the project certainly represented a significant factor in the effort: in fact, the Florentine firm had already built up an internationally-recognised know how in medical ablation techniques using lasers, and also offered the opportunity to plan a low-cost implementation of the product, which could very well be included in the batch production of biomedical lasers.

Accordingly, in 1996, the physicians started an extensive stage of analysis, for the most part on stone materials, which allowed El.En. to create a new laser product, modified with regard to both its impulse and duration (Siano et al. 1997).

The last puzzle piece in the innovation development was put by local institutions, who supported the testing and application of laser to restore pieces of the art present in the territory.

A further aspect to conclude this section concerns, in fact, the materials and works of art that were subject to the first experiments, and definitely provided a crucial input to the success of this venture.

The laboratory tests of laser application were carried out on an assorted typology of archaeological materials in stone and metal (Pini et al. 2000), while on-field testing mainly applied to stone and bronze materials. Initially, the laser technology had a certain degree of expansion precisely with applications to stone handiworks, and counted more than 14 restored artworks made of this material. On the contrary, later on, a high recognition was given to the restoration of some bronzes in Florence, certainly because of the value and number (more than 12) of these pieces, and the organisation of post-restoration museum exhibitions.[7]

5. The creative cluster for the innovation 'laser for restoration of cultural assets'

5.1. Funded projects

The twelve projects selected, whose object was by some means associated with the use of laser in restoration, allow us to reconstruct the various stages of the innovation process.

The research and development (R&D) activity was concentrated in the Nineties, particularly as regards stones and metals. The beginning of the Two-thousands were mainly characterised by the *in loco* testing and experimentation of laser technology, and the field of application was extended to include other materials, such as masonries, frescos and paintings. Finally, the innovation process is presently going through a period of exploration, searching new paths in the conservation and archeometric application of laser to cultural assets, with particular reference to metals.

The very first projects were led only by IFAC, in the framework of a series of initiatives taken by CNR, and were characterised by an intense activity of research, aimed at verifying the applicability of the technologies of photoablative laser to preservative restoration. Already at this initial stage, the Institute took in other actors carrying complementary competencies, such as restorers, physicists, chemists, laser specialists and experts in laser systems engineering, revealing its interdisciplinarity approach.

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[6] The CNR became IFAC-CNR only in 2002, while before this reorganisation it was called Institute of Quantum Electronics (Istituto di Eletronica Quantitisca, IEQ). We are always referring to IFAC-CNR only for the sake of exposition.

[7] Among the main bronze works of art restored in the Florence context, which later aroused a great interest in museum exhibitions, are the following: Ghiberti's Gates of Paradise, Verrocchio's David, Giambologna's Bronzetti, Danti's Bronzes, Rustici's Sermon of St John the Baptist, Donatello's David.

In 1997-2000, the programme of the Tuscany Region on Regional High-Technology Network marked a clue moment for the development of laser technology, for three particular reasons. First, the central unit of the partnership (IFAC, OPD, El.En.) was formalised and thus maintained for the following twenty years, in which it will invest time and resources trying to find new applications of this technology to the sector of restoration. Second, the implementation of a prototype was made, the so-called 'SMART CLEAN', which will then be produced and commercialised by El.En., and lay the groundwork for its further improvements and adjustments. Third, En.El. was enabled, thanks to the funding of this project, to invest in the production line of lasers for restoration.

In the course of the project, a comparison among different typologies of laser was made to choose the most appropriate for each kind of material to be restored, with the resulting identification of the various optimum methodologies, and their translation into parameters of laser emission for the use in restoration. But the really substantial step forward in the innovative process was the implementation of a prototype neodymium, the YAG laser (the above-mentioned SMART CLEAN). This had several innovative factors: it was transportable, and radiation was transmitted by an optic fibre cable, allowing a convenient use in restoration yards. In fact, the operator was enabled to direct the laser radiation precisely to the affected area by moving only the optic handpiece, and leaving the rest of the apparel still. A few tests were made at the Rucellai Palace in Florence and the Chapel of the Square in Siena, with very satisfying results for the Superintendences of both towns.

At that point (2000), research addressed a laser system capable of varying not only the strength and the repetition frequency of the impulse, but also its length, which would be a useful characteristics for restoring stones and other materials. The result was a prototype of neodymium laser YAG called 'VARIO', which was characterised by a variable length of impulse, and consequently a flexible use on different materials. R&D having progressed to such a good point and the tool having been tested, the network resolved to undertake technological transfer and started to involve a substantial number of firms, from both the restoration sector, and others, like diagnostics and ICT.

The project Optocantieri, (regional programme PRAI-ITT 2000-2004) was aimed at enlarging the network and starting to actually use laser technology, with the cleaning of some artworks from three sites: the Miracle Square (Pisa); the Old Palace and the cathedral Santa Maria del Fiore (Florence); the 'Fonte Gaia' (Siena). A key factor, in the latter case, was that end users were directly concerned, as they were given the possibility to try laser and validate its technology.

In parallel with the projects more typically addressed to R&D and technological transfer, the European funds allowed to undertake extensive networking and dissemination activities at international level. The ambition was to create an international, multidisciplinary community that would promote the recognised, validated use of laser for cultural assets restoration. The projects COST Action G7, together with the two Culture 2000 Programmes, represented an essential opportunity to open out to Europe, as they brought it into the international debate over the opportunities/threats deriving from the laser option, where it also tried and advanced a sort of 'Italian line' for the solution to the problem.

Finally, the latest developments in this field concern the exploration of innovative paths moving from the real demands of operators. Specifically, two projects were begun and are now under way, whose purpose is to diversify the application of laser in the area of cultural assets.

The first project, Authentico (2007-2009), was financed within the VI Framework Programme and is directed to an interesting, further application of laser technology: that is, to the mapping and dating of artworks, especially intended as an anti-falsification guarantee.

The second project, ST@RT (2008-2010), is financed by the Tuscany Region and is aimed not only at gathering the technological competencies relevant for cultural assets from all over the region, but also to develop R&D for new laser systems applied to restoration diagnostics and works.

Table 3 summarises the main information relevant to the projects analysed above.

INSERT TABLE 3 HERE

5.2. The actors

After having reconstructed the genesis and evolution of laser innovation, with a particular emphasis on the importance of inter-subjects relationships in its development, we now examine in details the role of the key actors in the setting off of the innovative process, and the (human, technical, scientific, financial and relational) resources involved in it.

The twelve projects selected covered a time frame of fifteen years (1995-2010) and incluede a total of 81 actors.

As regards localisation, it is interesting to remark that half of the subjects who took part in these activities are localised in Tuscany.[8]

The analysis of the typology of actors confirms that the greatest role for the innovation was played, on one part by research centres, and on the other by firms and institutional actors. On the whole, these three sets covered about a 88% of all actors involved, and in particular, there was a marked prevalence of the world of research (50% of the total), followed by the industrial world (21%), and the institutions (18%). It's worth noticing that the only large-sized firm is El.En., and the reason for that is that regional project funds are only granted to small and medium firms. This fact proves how this group relied so much in the idea and went so hard at it, as to invest chiefly its own resources.

The survey into the competencies of the participating actors shows that these projects required a broad multidisciplinarity. One third of the sample is composed of subjects directly connected with the field of preservation and promotion of cultural assets (20%), and restoration (15%). A significant presence is obviously that of optoelectronics (15%), being the economic sector owning the technical competencies for laser development. To complete the picture of the technical capabilities required, chemistry and physics registered a 11%.

Another relevant information concerns the financial resources to which the concerned agencies were admitted, where more than five million euro overall were invested into the twelve projects. The area that benefitted from the largest share of funds was Tuscany, where a 74% of the contributions were allocated. The actors who were destined the most part of public money were research centres (61%) and universities (19%), while firms, despite the fairly good incidence of their participation, received a little less than 6% of total resources.

Finally, some interesting cues are taken from the point of view of the competencies involved: apart from optoelectronics which, as it might be expected, had the highest share of financing (25%), the other actors to receive more funds belonged to diagnostics (20%) and ICT (19%), while smaller percentages were attained by chemistry and physics (7%) and restoration (5%).

5.3. The analysis of relationships

In this section, the relationships that the actors set in motion by participating to the twelve projects financed are examined. It is in fact possible, with the assistance of the Social Network Analysis, to sketch the frame of the network, the place occupied by each subject and the prevalent ways of relationship governance.

The participation rates of actors show again a prevalence of IFAC, who entered the partnership of eleven projects. As already mentioned, this data is partly affected by the methodology used to build the sample; nevertheless, it certainly well signify the great activity of the CNR institute in the planning stage. The figures for other organisations, such as OPD, the Department of Environmental Sciences of Siena University and the El.En. group, are also quite important.

[8] The actors located in Tuscany constitute the 43.2% of the sample, while 3.7% is scattered in the rest of Italy, 50.6% in the rest of Europe, and 2.5% are non-European.

Since 66 actors out of 81 (that is, 81.5% of the total) participated to only one project, we can infer a small cohesion, which signals the likelihood that the central unit that carried out the innovation activities is constituted by an extremely restricted number of actors.

The density indexes[9] show that the average number of projects to which each couple of actors co-participated was 0.3219, and that a 30.5% of the total number of couples were co-members in one or more projects.

These figures alone convey the image of a loosely cohesive network, especially if related to its small size, but it is also necessary to combine this information with the indexes presented below, which help to better define the network frame.

The first index is the degree of centrality, which corresponds to the number of direct connections a single actor has built. Under this profile, the network appears strongly centralised around IFAC, who co-participated to the projects with a total number of 78 organisations, that is with the 97.5% of all the actors. Other subjects who detain a certain degree of centrality are all foreign actors, and their central position in the network especially derives from their participation to the COST Action G7 alone. A worth-noting exception is offered by the cases of the Romanian National Institute of Research and Development for Optoelectronics (INOE-Romania), the Spanish Instituto de Química-Física 'Rocasolano' (IQFR), the Greek Institute of Electronic Structure and Laser (FORTH-IESL), whose visibility in the network is the result of more well-structured relations.

The second index is betweenness, 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. Also in this respect, IFAC maintains its central position, and is established as the coordinator – because of its part as well as its action – of the relationships developed through the planning activities. However, another visible feature is the significant presence of other local actors who work as intermediate centres and connectors: OPD and Siena's Department of Environmental Science present themselves as privileged interlocutors as regards laser development, as well as the Archaeological Superintendence of Tuscany (Soprintendenza Archeologica Toscana, SAT) and, behind them, Pisa's Department of Historical Science of the Ancient World, other CNR institutes, and El.En.[10]

The examination of the centrality indexes can be combined with the analysis of the relational topology as it comes out from a graphic representation of the network of the actors (Burt and Minor 1983) who participated to the twelve projects.

By looking at Figure 1, it is possible to make some interesting remarks. First of all, Institute of Phisycians clearly represents the most central knot around which the others catalyse: therefore, it is the actor who detains most (relational) power within the network and has a connector role.

INSERT FIGURE 1 HERE

Second, two macro-blocks take shape: the Tuscan one on the left and the European one on the right. In this regard, IFAC works as a 'bridge' between the local and the international levels. It can also be considered a so-called 'cutpoint', which means that once it is removed, the constituents of the network increase: in our case, for that event, they would become two – one with a marked local profile and the other European – and specifically, the actors who take on a first-rate role as connectors are SAT on the one hand, and INOE-Romania, FORTH-IESL and IQFR on the other.

Third, we can observe that the subjects who received the largest shares of funds for the projects (the biggest knots) are not necessarily the most central: if we look over the list of actors having a

[9] The density of a network is given by the proportion of the potential links actually at work, and measures the degree of connection for that network, in other words, its cohesion.

[10] The indexes of betweenness of the main actors concerned are the following: IFAC-CNR 1856.500; OPD 93.500; Siena's Environment Department 93.500; SAT 89.333; INOE-Romania 44.667; Pisa's History Department 22.667; CESVIT 22.667; FORTH-IESL 0,333; IQFR 21.333; Institute for the Conservation and Promotion of Cultural Goods (ICVBC-CNR) 17.000; Optic National Institute (INO-CNR) 17.000; Informatic Science and Technology Institute (ITSI-CNR) 17.000; El.En. 16.167; Restauro Italia 5.667.

higher betweenness and centrality, we can see that so many as 9 of them do not appear among the first 15 for financial resources received.[11]

The actors who participate to at least three projects (see Figure 2) are only 6, and those who take part to four projects are only 4 (see Figure 3). The pattern of the network presents a nucleus corresponding to that group of actors who offered an essential contribution to the development of the technology, thus confirming the previous analyses: they are OPD, IFAC, El.En. and the Siena's Department of Environmental Sciences. In this respect, it is important to assert the role of a 'triple-helical' lever of innovation (Etzkowitz and Leydesdorff, 1998).

In fact, the highest degree of participation, that is, in five projects, is registered only by three actors. It is also interesting to note that these subjects did not all participate to the same projects, and that OPD played the role of the main actor (connector) in the network, linking the Siena's Department with IFAC (see Figure 3)

INSERT FIGURES 2 AND 3 HERE

6. Conclusive remarks

The case configures itself as a successfull cases of technological innovation developed in creative *milieux* of art cities, by a set of economic, non-economic and institutional actors who identify a 'creative cluster' locally and internationally renown.

The genesis and development of the innovation under study can quite essentially be understood in terms of the interpretative model of the so-called 'creative capacity of culture' which, at a first approximation, can be intended as the ability to find 'unusual relatedness'. What was observed in our investigation can be recognised as an innovative path marked between novelty and renewing, where traditional sectors of high culture, like restoration, combine with emerging sectors of high technology, like medical diagnostics, and generate new ideas and advancements. The innovative idea comes out from an event that can be defined as a case of serendipity – starting from a hologram and ending up with a laser cleaning technology (unusual technological relatedness is at work) – and later develops through the cross-fertilisation among unrelated sectors like medical diagnostics and cultural heritage.

The main factors of the innovation process concerning laser applications for restoration of cultural assets can be summarised as follows.

The subjects involved in the innovation prove to have a marked collaboration and a propensity to share their knowledge. This feature made possible that the process to implement laser for restoration was fuelled not only by the relevant actors, but also by the context at large (according to an open-innovation approach rather than to one strictly linked to the innovations developed within the R&D laboratories).

In fact, a substantial prevalence of an interdisciplinary approach was observed, and a tendency to 'contamination' in actors from dissimilar branches of learning. Accordingly, the projects investigated are characterised by different, and sometimes complementary, competencies: chemists, physicists, restorers, art historians, geologists and engineers work together well, thanks to a few 'bridging' subjects, who manage to tune up their seemingly-distant communities.

Next to the positive effects due to territorial proximity, cognitive proximity had an important role. These effects arise from the main actors with their personal stories (*human dependence*), as well as from the organisations in which they work, and the territory in which they live – that is, the art city – where they join to form a sort of *path dependence*.

The involvement into the development process of a 'triple-helix that moved the innovation forward constitutes another factor deserving notice, as it can be immediately inferred from the

[11] An only partial explanation to this fact is given by the presence of actors who may participate on a zero-share basis, like public bodies (OPD and Superintendences) or large firms (El.En.).

examination of the research projects and the interviews done. The success of the initiative was certainly prompted by the joint concurrence of the worlds of research, industry and institutions.

The resulting model of innovation governance was put into effect with a real technological transfer, to be regarded as an economic and organisation process directed to the final realisation of a product. In this direction, it is indeed possible to read the overwhelming activity of R&D that made its way into the projects, and later, thanks to the synergy with a keen sense of entrepreneurship, brought the solution to a tangible problem (the cleaning of works of art with a practical and mini-invasive method) with the manufacture and commercialisation of a product (the laser equipment).

Another valuable factor is the strong local rooting of many actors, together with their network of relations, fairly stable and based on trust. This situation probably favoured the carrying out in parallel of the research stages for experimentation on the one hand, and application and validation on the other. In other words, the innovation process was driven along a 'circular' development, rather than through the traditional, linear sequence 'research-development-production-commercialisation'. In our case, the product's development stage provided repeated feedbacks to the process, and redirected research to new mixes of the existing know how, allowing to refine the laser equipment with more and more well-suited parameters and further practicable uses.

Finally, it is worth to remark that end users (preservation and protection agencies, museums, restorers, and the like) played a significant role in the process. The steadiness of their attention at the development of laser technology allowed research to begin with a real problem and go on without losing the tracks that were laid by the needs of restorers, for example by adjusting the ergonomic parameters and improving the use of laser apparels.

To conclude, the case study has shown how culture can rejuvenate a mature sector like that of restoration, and thus generate innovations; therefore, it constitutes a good example supporting the notion of a new phase in the relationship between culture and economy, that is, what is called the 'cultural enhancement of economy'. Aside from the specific case, many theoretical inferences can be made from this position, shifting the attention from the issues of culture and local development to those of economy of creativity and innovation.

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TABLES AND FIGURES

Table 1 – The evolution of the relationship between culture and economy

Economic enhancement of culture	**Cultural enhancement of economy**
• Culture as an asset • Culture as a factor of production • Focus on artistic, cultural and environmental heritage • Rise of cultural industries • Rise of cities of art and culture • Rise of cultural cluster and district • Focus on local economic development	• Culture as capacity • Culture as sources of innovation • Focus on human capital, creative class and ICT • Rise of creative industries • Rise of creative cities • Rise of creative cluster (*milieu*) • Focus on innovation process

Source: our elaboration

Table 2 – The paths for the creative capacity of culture

Renewing	**Novelty**
Urban Renewal • City branding • Physical renovation and flagship developments • Culture-led and driven strategies	*Cross-fertilisation* • Inside a cultural cluster/district • Among 'related' cultural cluster/sectors • Among 'unrelated' clusters/sectors • Across time (the rebirth of a cultural district)
Economic Renewal • Industry regeneration • Profession rejuvenation	*Serendipity* • New uses • Multiplicity of interests • Technological correlations

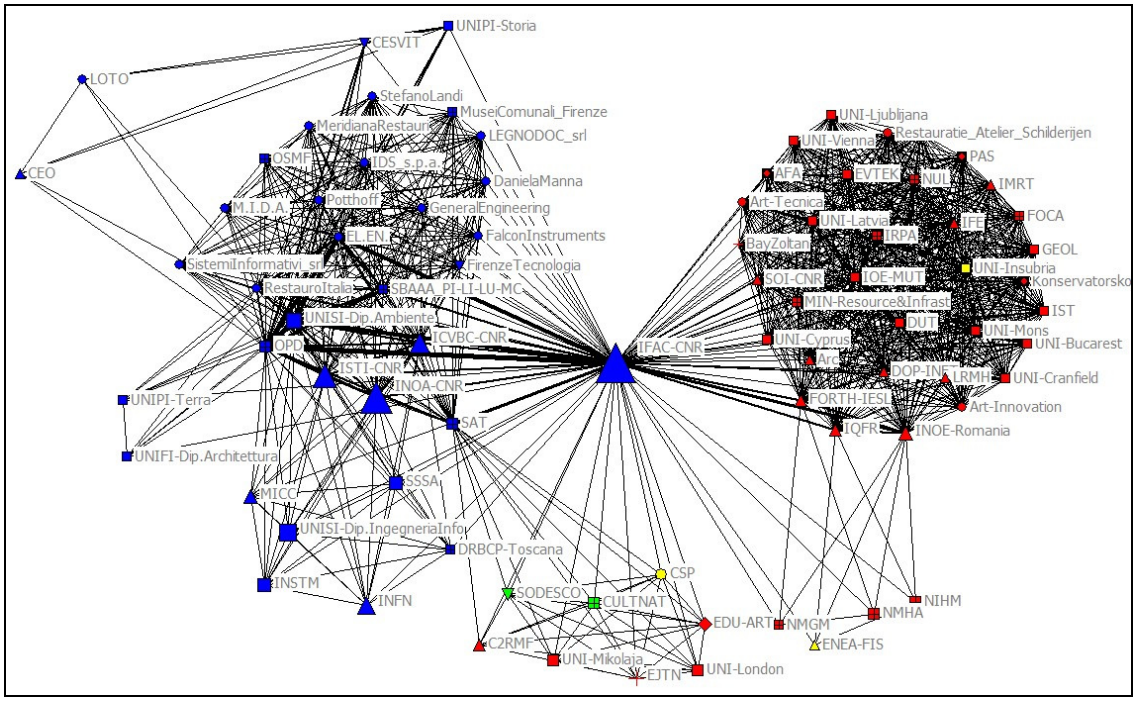
Source: our elaboration.

Table 3 – The twelve projects that developed laser for restoration

Project denomination	Funding body / Call for tender	Years	Coordinator	Partners	R&D activities	Materials under restoration
Photoablative techniques in preservative restoration	CNR Strategic Project CNR 1995	1995	IFAC-CNR	1	Applied Research and Experimental Development	Stones
Development of laser cleaning methodologies and systems for preservative restoration of art handiworks	CNR CNR Finalised project 'Cultural Heritage' 1996-2001	1996-1999	IFAC-CNR	1	Applied Research and Experimental Development	Stones
Laser techniques and systems for cultural assets restoration	Tuscany Region Technology Network RRAT -1 1997-2000	1998	IFAC-CNR	6	Applied Research and Experimental Development	Stones, metals, paintings
Laser equipment for preservative restoration of coatings and art handiworks	Tuscany Region RRAT-2 1997-2000	1998	Optronic Excellence Centre	6	Applied Research and Experimental Development	Stones, metals, paintings
Neodymium laser system YAG for restoration metal handiworks	Tuscany Region RIS + Tuscany 2000-2001	2000	IFAC-CNR	4	Experimental Development	Metals
Pilot restoration yard 'Cleaning of the façade of St. Frediano Church in Pisa'	Tuscany Region RIS + Tuscany 2000-2001	2000	Restauro Italia s.r.l.	8	Testing	Stones
Artworks conservation by laser	EC COST Action G7	2000-2006	FORTH-IESL (2000-2003) IFAC-CNR (2003-2006)	35	Networking and dissemination	Various
Optocantieri	Tuscany Region PRAI-ITT	2002-2004	IFAC-CNR	23	Technological transfer; Networking	Masonries
Advanced on-site restoration laboratory for European antique heritage restoration	EC Framework Programme 'Culture 2000'	2003-2004	National Museum of History and Archaeology (Constanta)	5	Search for synergetic restoration techniques and methods	Frescos, wood paintings
Saving sacred relics of European medieval cultural heritage	EC Framework Programme 'Culture 2000'	2005-2006	INOE-Romania	5	Testing	Frescos, wood paintings
Authentico	EC VI Framework Programme	2007-2009	European Jewellery Technology Network	10	Applied Research and Experimental Development	Precious and non-precious metals
ST@RT	Tuscany Region CIPE Funds	2008-2010	INOA-CNR	12	R&D; Networking	Monuments and painted façades

Source: our elaboration.

Figure 1 – The network of laser for restoration (c ≥ 1)*



Legend: the different colours of knots show the *site*, which is blue for Tuscany, yellow for the rest of Italy, red for Europe, green for non-European countries; the different shapes of the knots show the *typology*: a triangle for research centres, a square for universities, a circle for firms, a plus sign inside a square for the agencies, a coloured circle inside a square for academies, a plus sign for associations; the dimension of each knot is a proportional representation of the *financial resources received*.

* The value expressed by 'c' stands for the minimum number of projects each couple of actors share.
Source: our elaboration.

Figure 2 – The network of laser for restoration (c ≥ 3)

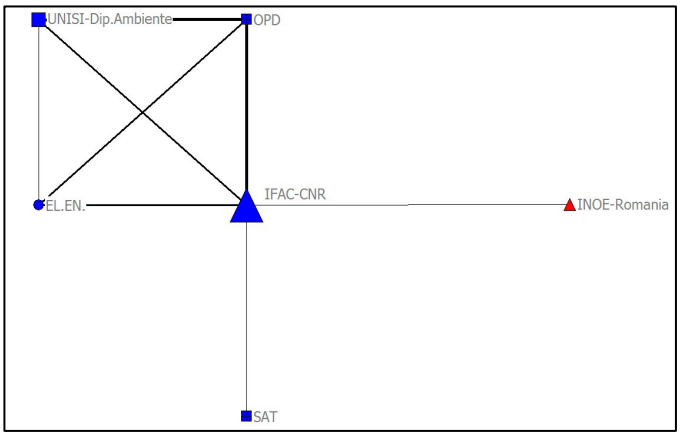
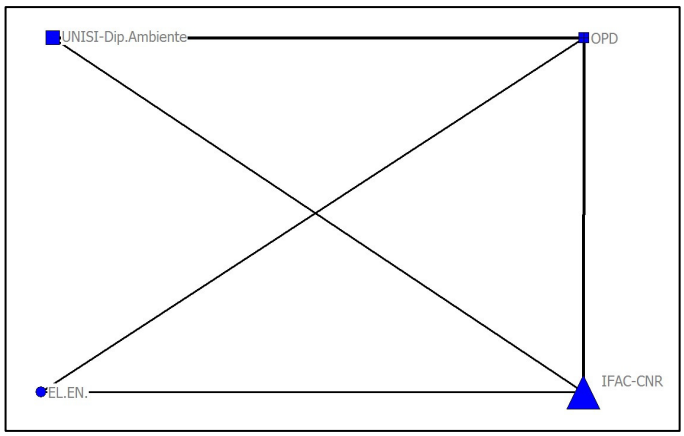


Figure 3 – The network of laser for restoration (c ≥ 4)



Source: our elaboration.