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Resilience, creativity and innovation: The case of Chemical innovations after the 1966 Flood in Florence[1]

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Abstract

Over the last decade, the debate on Evolutionary Economic Geography has been enriched thanks to the ecological approach and its application to the concept of resilience to social systems. Resilience is not only the capacity to absorb shocks and maintain functions, but also includes the capacity for renewal, reorganisation and development. This "adaptive capacity" may be consider in creative approaches as a "creative capacity" able to generate ideas and innovations after a shock, in a creative milieu such a creative city.

This paper aims to contribute to the still under-researched debate on resilience and innovation, integrating the resilience approach with the creative one, and developing the still neglected idea of a creative and resilient city. We focus on the city of Florence and on the innovations in conservation sciences developed after the 1966 flood.

Combining these perspectives, we consider the city of art as a creative and resilient system, not only to absorb shocks, but also to transform ad renew itself through a "creative adaptive capacity", where the cultural and art heritage may be both a source for innovation and a source for resilience.

We investigate lateral and transversal innovations developed from cross-fertilisation processes in the scientific and humanistic knowledge embedded in the territory. In particular, we focus on the innovations in chemistry in conservation sciences of cultural heritage developed by a scientific network rooted in Florence. The flood was the starting point for the rise of a new innovative trajectory, forming a new scientific niche in modern conservation sciences.

Keywords: Resilience, restoration, cultural heritage, chemical innovations, flood, Florence.

JEL: O31, L65.

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1. Introduction

With the increase of environmental disasters (Zolli and Healy, 2013) and the sharpening of the current economic-financial crisis, the issue of resilience has become of great topical interest in the economic field, somehow bypassing the traditional paradigm focused on growth and competition and drawing attention to other forms of sustainable development (Bristow, 2010). The debate was started by some economists who engaged in the study of the relationship between vulnerability and resilience in some small countries, like Singapore, and highlighted their unexpected ability to respond to globalisation's challenges (Briguglio et al., 2009). Even culture and creativity have been considered a cure-all for the crisis because of their ability to generate ideas and innovation for a sustainable development. At first, scholars drew attention to the creative class and the creative cities, and afterwards to the cultural and creative clusters and industries (Cooke and Lazzeretti, 2008). Basically, creativity and resilience are two significant processes embedded in societies and territories which are worth analysing with a time-space evolutionary perspective in order to identify new forms of sustainable development.

The definition of these concepts is still ambiguous and their fuzziness has often been attributed to their multidisciplinary nature (Markusen, 1999; Scott, 2014), which on the one hand contributed to their popularity (Markusen et al., 2008; Pendall et al., 2010), but on the other has attracted much criticisms (Hassink 2010; Hudson, 2010; Pratt, 2010).

Amabile (1966) in his seminal work argues that creativity is the starting point for innovation and a necessary but not sufficient condition for a successful one. Creativity is the production of novel ideas in any domain, whereas innovation is the wider process of both generating and applying creative ideas to obtain an outcome for the market.

Resilience stretches back to the ecologist Holling (1973). He distinguishes between engineering and ecological resilience: the first is the ability of a system to return to pre-existing equilibrium after a disturbance; the second is based on multiple equilibria: ecosystems are in fact able to respond to perturbations by changing their structure and functioning as a new system.

Scholars in social and regional sciences prefer the ecological perspective of resilience to study the dynamics of social-ecological systems (Swanstrom, 2008; Folke, 2010). Some authors review the different definitions of resilience and their potential application to explaining the long-term development of urban and regional economies, applying the adaptive cycle model from the panarchy theory (Simmie and Martin, 2010). Others explore the value of the resilience framework to investigate how metropolitan areas respond to challenges (Evans, 2011). Resilience, adaptability and transformability are considered the three related attributes of social-ecological systems that determine their future trajectories (Walker et al., 2004), and the key factors for studying the relationship between innovation, global change and territory (Cooke and Eriksson, 2012) as well as path dependence (Simmie, 2012).

In our perspective, according to Hollings (1973), resilience is not only the capacity to absorb shocks and maintain functions, but also includes the capacity for renewal, reorganisation and development. This "adaptive capacity" may be consider in the creative approach as a "creative adaptive capacity" able to generate ideas and innovation after a shock, in a creative *milieu* such a creative city (Lazzeretti 2012a).

This paper aims to contribute to the still under-researched debate on resilience and innovation combining the resilience and the creative approaches, and developing the still neglected idea of a creative and resilient city (Pickett et al., 2014). Combining these perspectives, we consider the city of art as an ecosystem where the cultural and art heritage may be a source of innovation, but also a source for resilience.

We investigate lateral and transversal innovations developed from cross-fertilisation processes, involving the scientific and humanistic knowledge. In particular, we focus on the chemical innovations for the conservation of cultural heritage developed after the 1966 flood by a creative scientific network rooted in Florence.

We find that the flood was the starting point for new innovative trajectories within the modern conservation sciences. A new paradigm arises after the 1966 flood, which shifted from a reversible to a compatible idea of restoration involving both humanistic and scientific disciplines (Brandi, 1963). This approach made the Italian school renowned worldwide not only for scientific reasons, but also for the value and the fame of the cultural heritage restored.

2. Resilience and creativity: toward an integrated approach to innovation

Both creative and lateral thinking[3] (De Bono, 1973) and resilient thinking (Zolli and Healy, 2013) reject the "engineering perspective" for investigating the

[3] Vertical thinkers take the most reasonable view of a situation and then proceed logically and carefully to work it out. Lateral thinkers tend to explore all the different ways of looking at something rather than accepting the most promising ones and proceeding from that. (De Bono, 1973).

transformation/adaptability of a system after an innovation process or a shock. In fact, in urban and regional studies, "ecological resilience" represents the prevailing view as opposed to the engineering definition. Similarly, in the innovation studies, the established approaches based on vertical thinking typical of close innovation paradigm are substituted by a creative approach based on lateral thinking and the new open innovation paradigm (Chesbrough, 2003). Innovations are thus also generated in specific contexts, and not only in R&D laboratories. Transversality, and the search for "unusual relatedness", which is often inspired by chance events, are some of the determinants of transversal innovation fostered by cross-fertilisation processes and serendipity. These processes are analysed by both geographers of innovation and creativity, and researchers in path creation and interdependence (Simmie, 2012, Cooke, 2012a) or the innovative capacity of culture (Lazzeretti, 2009).

Finally, we should remember that both approaches assign a prominent role to the human and social capital. Florida (2002) underlines the strategic relation between the creative class and the development of a creative city, while Campanella (2006) argues that urban resilience is largely a function of resilient and resourceful citizens.

Therefore, starting from the idea that the two approaches can usefully complement each other in the study of resilience, particularly in creative and resilient cities, we recall the current state of the art on this still-neglected issue.

The creative approach has produced a vast literature on the concept of creative city, while that of resilience has not been equally treated, having being discussed only recently more like a metaphor.

Creative cities are usually investigated with respect to four key factors: the creative class, the cities themselves, the creative clusters and the creative industries. Scott (2013) underlines that the cities emerging in the third millennium would need a new sort of cognitive-cultural capitalism. Pratt and Hutton (2013) highlight the critical aspects associated with the relationship between creativity and finance. Zuckin (2012) discusses the risks involved in globalisation as regards the DNA of cities, i.e. the possible loss of their authenticity and identity. Sasaki (2010) emphasizes the employment of culture in terms of social cohesion and inclusion. In a nutshell, a return to a societal function of cultural heritage is advocated for a culture-driven sustainable development taking into account – among others – environmental risks (Lazzeretti, 2012b).

At present, the concept of resilience has not fully entered into this debate, and the rare exiting essays do not go to deep into the issue, seen mostly as a metaphor.

Some scholars have started to underline how creative professions are more resilient, as culture-related jobs require a greater adaptability and versatility facing globalisation challenges (Ibert and Schmidt, 2014). Other surveys suggest that cultural and creative industries are more resilient compared to other sectors because they react better to the recent economic gloom (UNCTAD, 2010). Others are instead starting to discuss localisation economies, arguing that creative industries located in the outskirts are more resilient than those traditionally set in the centre of creative cities (Felton et al., 2010).

Anyway Glaeser (2005) suggests that if successful cities were not "resilient" they would not survive. However, it is also true that the recent intensification of both environmental and economic disasters raises the question again, and more sharply. Among urban planners, we can mention Vale and Campanella (2005), who define the resilient city as a city that resumed its previous function and growth trajectory after a lag. Recently, two different typologies of resilience have been distinguished: the first refers to the ability to survive shocks, like Nagasaki after the Atom bomb or New Orleans after the hurricane Katrina; the second concerns the ability to change in the face of shocks, like the cases of Boston or New York that managed to reinvent themselves over time (Glaeser, 2005).

In the Evolutionary Economic Geography (EEG) approach (Boshma and Martin, 2010) resilience is an important factor in the study of growth and decline dynamics in local economies, giving a better understanding of the relationship with the innovation capacity (Clark and Walsh, 2010). Davies (2011) identifies three types of reactions: the ability of a regional economy to withstand external pressures, its capacity to respond positively to external change, and its long-term adaptability or learning capacity (Pendall et al., 2010; Pike et al., 2010). Simmie and Martin (2010) discuss the different features of resilience, like a regional economy's sensitivity or vulnerability to shocks, and make a distinction between inherent resilience under normal circumstances and adaptive resilience under crisis situations. In the field of cluster evolution, Martin and Sunley (2011) follow the approach of the adaptive cycle's sensitivity or vulnerability to shocks in a regional economy, taking into account three key variables, resilience, connectedness and capital accumulation, and identifying four phases in the cluster evolution: reorganisation and restructuring, exploitation and growth, conservation, decline and release. Later, in his in-depth investigation on economic resilience and hysteria, Martin (2012) offers a new classification: resistance, renewal, recovery and re-orientation. As to the relationship between resilience and innovation, in his many contributions on eco-innovation, Cooke (2012b) complements the study with the approach of the complexity theory, and examines thoughtfully the relationships of relatedness, transversality and cluster transformation with regional innovation systems. Wolfe (2010), studying the case of four Canadian cities, underlines the role of cross-fertilisation and path dependence. The latter concept was specifically scrutinised by Simmie (2010), who integrates the adaptive cycle with the path-dependence theory, and goes deep into the various phases of the innovation process. Among these, he identifies a phase of path creation, which is of special interest to us because of the key notions of historical accident, chance event and serendipity. In this framework, the niches are locations where it is possible to deviate from the rules of the existing regime (Geels, 2004) and may be regarded as an important minority selection environment in which the process of a new path creation starts (Simmie, 2012).

In this scenario, our aim is to consider the role of resilience in the innovative process that follows an external shock. Therefore, we position our analysis in the adaptive cycle's phase of renewal, which measures the extent to which regional economy (a city of art, in our case) renovates its growth path (Martin, 2012). In this phase, resilient and creative lateral thinking can jointly start up, sometimes even by chance, virtuous processes of cross-fertilisation leading to new innovative trajectories. These will be favoured by the presence of an extensive heterogeneity/variety of resources, by relatedness, transversality and path dependence, which are vital to develop an innovative adaptive capacity. Therefore, resilience may have a strategic role in triggering creative processes at times of great discontinuity, like in the aftermath of catastrophic events, placing itself in the so-called "white spaces" (Cooke and Erikson, 2012) and launching new innovative trajectories.

Ecologists consider that the capacity for resilience is expected to be low at high connectivity levels and under the predominance of conservative components in the system (release and decline phase); *vice versa*, a high degree of resilience is associated with the capacity of a system to reorganise and rebuild resources when the connectivity is low but increasing (reconstructing and renewal phase) (Holling and Gunderson, 2002). According to Cadenasso et al. (2006) in a resilient ecosystem three main factors should be taken into account: heterogeneity, connectivity and history.

These three characteristics have a crucial role also in the city. The creative city is an ecosystem that feeds on the historical, sedimented knowledge, the variety of the resources accumulated and the connection ability, which make possible to absorb external shocks, to change and to move on.

In literature, innovation geographers consider the heterogeneity of a system like a variant of the so-called approach of related variety (Frenken et al. 2007), which represents a cornerstone of the EEG; in the studies of creativity, heterogeneity is taken into account within the concepts of variety and diversity (Lorenzen and Frederiksen, 2008), being associated to the variety of the cultural resources existing in a specific place. The issue of systems' connectivity must instead be looked at from an opposite point of view as compared to that of creative thinking[4]. The innovative capacity usually increases with higher variety and connectivity, as proved by the rate of innovation attained in cultural clusters and networks favoured by a Marshallian creative atmosphere (Bertacchini and Santagata, 2012) In what concerns the role of history, we recall that in EEG studies path dependence is a process influenced by history, and historical accidents are one of the pillar of the path-creation phase (Simmie, 2012). At to the creative approach, history is traced back to the process of preservation and improvement of a place's heritage, which includes a symbolic value and is seen not only as an asset to preserve but also as a source of innovation and resilience (Bandarin and Van Oers, 2012).

Starting from these considerations, we will try and examine the "creative adaptive capacity" after a shock in a city of art and the innovations connected with it. We focus on the Florence flood of 1966 and on the innovations developed by a specialised network for chemistry in conservation science. We try and answer to the following empirical and theoretical questions:

– Which are the new innovations developed after the 1966 flood in Chemistry in Conservation sciences and who are the leading innovative actors?
– Which theoretical implications are behind these outcomes, in terms of relations between resilience and innovation, and ultimately for the design of a "creative and resilient cities"?

3. Research design and methodology

From a methodological viewpoint, most of the evolutionary studies conducted on urban and regional resilience focused on the long-term evolution of regions and local

[4] Simmie and Martin (2010) discuss the idea of "connectedness", where the more internally connected is a system, the more structurally and functionally rigid and less adaptive it is. A downward shock to one or just some of a region's industries may well ripple through and have consequential depressive effects on much of the region's economy as a whole.

systems through time series analysis (Simmie and Martin, 2010). The variables used are mainly those related to the evolution of population, employment and unemployment, and the like (Pendall et al., 2010).

Instead, our interest lies in two areas which have not been sufficiently examined so far, that is the study of innovations and of networks.

The studies of innovations are mainly founded on qualitative analyses, such as the innovation biographies applied to eco innovations (green economy) (Cooke and Eriksson, 2012), although there are some comparative quantitative studies like those of patenting, which use Markusen's industrial district taxonomy (1966) to measure regional innovation (Clark and Walsh, 2010). Biographical researches and life-history approaches constitute a field of social science developed both in the creative and the geographical approaches. Vinodrai (2006) followed the career paths of the designers based in Toronto to show how the high circulation of talent and related knowledge flows in the local design sector. Törnqvist (2004) illustrates the biographies of Nobel laureates with time-geography diagrams to examine the importance of innovative places for the careers of individuals. Recently Porter et al. (2013) investigated with a complex adaptive system approach the case of photonics in Wales as an example of a transversal innovation by cross-fertilisation, and focused on understanding what prompts path interdependence and how this interdependence occurs.

The study of innovation networks usually follow an evolutionary perspective (Vicente et al., 2011) and are very helpful to analyse diversity/related variety, transversality and cross-fertilisation of innovative processes (Cooke, 2012a). Their relevance for regional resilience has been recently highlighted (Boschma, 2014) and some scholars of the network approach analysed the structural properties of local knowledge networks in order to understand the conditions of regional resilience (Crespo et al., 2013). Also, the recent bibliometric analyses of scientific communities provided a useful exploration of cross-disciplinary paths, which turned very valuable for the study of cross-fertilisation experiences involving academics as well as firms (Baba et al., 2009).

In this study we integrate the approach followed by innovation geographers (innovation biographies) with the recent bibliometric studies applied to the evolution of concepts and scientific discoveries (Lazzeretti et al., 2014) with the aim of identifying the scientific innovation networks relevant to both EEG studies and the creative approach (Ter Wal and Boschma, 2011; Belussi and Staber, 2012).

We retrace the story of the innovations in chemistry in conservation sciences – going from the Ferroni-Dini method developed after the 1966 flood to the present nanotechnologies – in the cluster of technological restoration, and go deep into the role of the innovators' network represented by the Florentine scientists of the Ferroni group.

The starting point of the research are the conservation sciences started after the Florence 1966 flood. A new philosophy of restoration (Brandi, 1963)[5] was then developed, which involved both humanistic and scientific disciplines and made the Florence school a case of excellence at worldwide level (Baldini, 1978).

The first study we led followed a creative approach and focused on the case of laser technologies in conservation, which were implemented by a creative cluster located in Florence (Lazzeretti et al., 2011). The innovations we analysed constituted very good examples of cross-fertilisation and serendipity processes stemming from lateral thinking.

This second study, which sticks to a resilient and creative approach, is centred on the innovations in the chemical field. In this sense, Florence can be considered a creative and resilient city, having the ability to adapt to external shocks (adaptive capacity) and start new innovative paths.

The resilience of the city, considered as an ecosystem, may be attributable to the three main factors: heterogeneity, connectivity and history (Cadenasso et al. 2006). For the case under study, these factors can be summarised as follows.

Heterogeneity can be associated to both the variety of resources and the scientific and humanistic knowledge embedded in the territory, which on the whole represent the city's heritage, whose symbolic value takes into account the history as well as the value system rooted in the city. This heritage can be summed up in the so-called "renaissance vision" of knowledge production, which by combining art and science can give place to innovative processes, even of a radical kind.

Connectivity can instead be drawn back to the set of economic, non economic and institutional relationships set up to promote the heritage's conservation and economic enhancement, given the presence of cultural and creative clusters and networks.

The analysis of innovations is based on secondary data (information, publications, research projects, restoration projects, etc.) and semi-structured

[5] This approach constituted the *incipit* of modern conservation sciences, which later on developed in the fields of Physical chemistry and in the application of new technologies, as well as in humanistic disciplines.

interviews conducted with the Snowball method (Goodman, 1961) during the second semester of 2012 with the main strategic actors in Florence. The first interview took place with a privileged subject, Piero Baglioni, full professor of Physical chemistry at the University of Florence, affiliate of the Massachusetts Institute of Technology (MIT), and presently representative of the restoration chemistry group of Florence. We also interviewed other leading personalities in the innovative process, among them: the physicist Renzo Salimbeni, ex director of IFAC-CNR and present representative of the Florentine technological cluster for restoration of cultural heritage; professor Luigi Dei, currently director of the Department of Chemistry of Florence University; Rodorico Giorgi, researcher at the same department, and expert restorers of the Opificio delle Pietre Dure; Leonardo Borgioli, PhD in Chemistry in conservation and today technical director of a private company of restoration products and services (which also distributes the main industrialised products developed by the Department of Chemistry as nano-lime, nanogel, etc.).

The analysis of relationships focuses on the scientific links connected to the developed innovation and was conducted through a bibliometric analysis of publications using SNA (Wasserman and Faust, 1986) meant to highlight the role played by scientists. We built the survey on an ad hoc database, drawn from the bibliometric analysis of papers, articles, proceedings published by one of the main Italian organisation in Chemistry applied to the conservation of cultural heritage, the Research Center for Colloids and Nanoscience (CSGI)[6]. We selected over 148 contributions about our issues from the first 1990s to the 2014, and analysed more than a hundred researchers affiliated to 13 universities. The resulting network involved more than five hundred Italian and foreign authors.

4. Chemical innovations in conservation sciences: a time-space perspective

4.1. The main chemical innovations in conservation sciences after the 1966 Flood

The development of chemical innovations in Florence started following the 1966 flood, a calamity that washed away the city, with terrible consequences for its

[6] The CSGI is officially recognised by the Italian government in 1994, and is under the supervision and control of the Italian Ministry for University and Scientific Research (MIUR). It includes 13 different universities across Italy. (http://www.csgi.unifi.it).

inhabitants as well as its cultural and art heritage (Paolucci, 1986). Florence was entirely flooded, about two third of works of art, museums, monuments and libraries reported damages. The so-called "mud angels" rushed from all over Italy and the world, and a new season opened for an ample debate on the effects of environmental disasters for cities of art, and particularly for restoration (Gden, 1979).

At that highly dramatic period, while the debate could still stand up to any criticism, even "unusual" solutions would fit the emergency situation. In this scenario, one of the main problems the scientific community had to solve was the restoration of works of art and monuments damaged by the prolonged immersion under the flood's water and mud. The problem with frescos, for example, was particularly critical: given the impossibility of an *in situ* restoration the paintings had to be detached and placed in special locations (Paolucci, 1986).

The development process of chemical innovations started in this period, just together with other innovations linked to the new paradigm of the so-called *modern* conservation sciences (Brandi, 1936). A pioneering role was played in this respect by the professor of Physical chemistry Ferroni, in a wave that propagated until today with the scientists forming what we will call from now on the Ferroni Group.

In what follows, we will retrace the history of the main innovations produced from the end of the 1960s onwards (Tab. 1).

Tab. 1 – Chemical innovations in Conservation Sciences

Period	**Innovation**	**First application**	**Problems (solving)**
1960s-70s	Tributilphosphate	Cenacle of Gaddi, Santa Croce Church, Florence	"Detachment" of the fresco with the traditional methods unfeasible
1970s	Ferroni-Dini method	"Crucifixion" of Beato Angelico, Capitular Hall of Saint Mark in Florence	Frescos crumbling and deteriorating because of excessive salts
1985s	Microemulsions	Paintings by Masaccio, Masolino and Lippi, Brancacci Chapel	Wax on frescos and paintings, pictorial parts
1990s	Autogenous mortar	Paintings by Masaccio, Masolino and Lippi, Brancacci Chapel	In-depth consolidation
End of 1990s	Nano-lime	Mural paintings in the Great Spanish Chapel of Saint Maria Novella	Applied nanosciences. Evolution of the Ferroni-Dini method
End of 1990s	"Revised" micro-emulsions	Guasconi Chapel, Church of Saint Francis, Arezzo	Evolution of micro-emulsions used to extract polymeric resins from frescos

			and murals and treatments with Paraloid
2000s-onwards	Gel systems	Oil painting on wood canvas of "Saint Stephen" by Ludovico Cardi, called "Il Cigoli"	Evolution of the previous methods

Source: our elaboration.

1) First innovation. Tributilphosphate and the Cenacle of Gaddi in Florence: cross-fertilisation from nuclear chemistry (1960s)

After the flood, the first important experiment developed by professor Ferroni was the attempt to restore *in situ* the Cenacle of Taddeo Gaddi, in the refectory of the Santa Croce Church, a work of art particularly deteriorated because of the long immersion in water and the disintegrating action of salts and nitrates. Unfortunately, it was not possible to proceed with the common procedure of detaching layers with glue, because Gaddi's work was so much contaminated by nitrates and phosphates that glue did not solidify, making the separation unfeasible[7].

Having learnt of the steady process of decay, professor Ferroni turned to the Superintendence, leaving at its disposal his competencies and sharing some personal opinions about the solutions to the problem. After having analysed the work of art, he suggested the use of *Tributilphosphate*, a chemical substance (used in nuclear chemistry to enrich uranium) capable of isolating nitrates. According to the possible assumptions, this substance would have led to the solidification of glue and thus facilitated the subsequent detachment. At first, given the relevance of Gaddi's work, the permission to operate on the fresco was not granted; however, by the end of the 1960s, given the persistence of the state of deterioration, the Superintendence authorised the chemical treatment on the painting.

Professor Ferroni set off a collaboration with the renowned restorer Dino Dini and together they applied Tributilphosphate to the painting so as to remove nitrates and proceed with the detachment of the fresco. The operation turned out well and the fresco safely took down: the chemical treatment had been successful and the painting could be cleaned and restored with the traditional methods (Ferroni and Dini, 1968).

[7] The operation consisted in the spread of hot glue over the fresco, which was taken off the wall once the glue had firmed up. Only later, new findings reveal that glue could not solidify not because of humidity, but for the strong presence of nitrates and phosphates in the Arno's water as well as in the soil of the nearly cemetery that had covered the Church of Santa Croce.

From this time onwards, the intervention of the research group of professor Ferroni continued to offer solutions to many critical situations with cultural assets. This first application promoted the Chemistry applied to restoration, which will have a more and more relevance in the future; at the same time, the Ferroni's research group started being a point of reference for the Chemistry in conservation sciences, particularly in what regards compatible restoration (Dei, 1999)[8].

2) Second innovation. The Ferroni-Dini method and the Cenacle of Gaddi in Florence cross-fertilisation from Physical Chemistry (1970s)

A second intervention, similarly important, concerned the post-detachment treatment. In fact, frescos, once detached from the wall, had to be restored following the traditional methods, but these proved ineffectual in reducing the concentration of nitrates and sulphates. The Ferroni's research group found the solution in a chemical process, i.e. the application of Barium hydroxide in water solution (Ferroni et al., 1969)[9].

The method consisted in the application of a stabilizer, which could refresh the work's pictorial layer. Its main characteristic was that the chemical-physical composition of the Barium hydroxide solution was compatible with frescos, which are made of the same substance (Baglioni et al., 2003). In due time, given its achievements, the method will be renowned as the Ferroni-Dini method (Ferroni and Dini, 1977). After forty years from its creation, it is still used and represents one of the emblematic examples of the scientific application of an absolutely compatible modern conservation science. On this subject, the Opificio delle Pietre Dure, an institution that is internationally renowned for its competencies in restoration, remarked that it was even "an emblematic scientific experience, that should be counted among the greatest discoveries made in the last few years in the field of frescos' restoration" (OPD, 2012).

The Ferroni-Dini method has been adopted all over the world in different situations and with excellent results, verified even many years after restoration. The method has been applied with the same excellent results to the wall paintings' pre-consolidation,

[8] In the scientific world, two methods are usually distinguished in conservative restoration: compatible and reversible restoration (Oddy and Carroll, 1999; see also below in this section).
[9] This is a consolidation technique that acts on the degradation produced by sulphates by renewing the binder of the pictorial layer. Therefore, it represents a valid alternative to the treatments with synthetic glues and resins, whose compatibility and durability is really bad.

as well as stone consolidation, and conservation of mortars, stuccos and mosaics (Baglioni et al., 2003).

3) Third innovation. Micro-emulsions and the Brancacci Chapel. Cross-fertilisation from chemically-enhanced oil recovery (1980s)

A third intervention was the restoration of the wall paintings by Masaccio, Masolino and Lippi in the Brancacci Chapel, in the Santa Maria del Carmine Church of Florence. One of the main criticalities with these frescos was that they had been repeatedly reached by wax squirts, caused by the putting out of candles. This evidenced the growing involvement of chemists in the restoration of cultural assets made by local institutions, a concern that will more and more increase in the future.

At the time, a former student of professor Ferroni, professor Baglioni, following the petrol crisis, was developing a thesis about micro-emulsions that could optimise the extraction of petrol from porous soils (*enhanced oil recovery*) (Carretti et al., 2005). Once again, the innovative idea develops from cross-fertilisation processes, this time derived from chemistry applied to oil recovery and also linked to the period Baglioni spent studying these subjects in the USA. It was then decided to apply micro-emulsions to wax squirts so as to remove this material from paintings. The operation succeeded with no damage to the work. This method was then refined over time and its Italian patent registered in 1991 (Ferroni et al., 1991).

4) Fourth innovation: autogenous mortar and the Brancacci Chapel (1990s)

In this period, in restoration, there is a passage from a "reversible" approach, which is typical of the 1980s and was later subject to wide criticisms, to a so-called "compatible" one (Oddy and Carroll, 1999), i.e. using methods well-matched with the chemical-physical structure of the work[10].

Starting from the first 1990s, the activity of the Ferroni group has intensified and expanded, carrying on the study and application of chemical compounds to cultural assets with the aim of making restoration as much as possible chemically compatible with the object. New methodologies are implemented, starting from the testing of the effects of autogenous mortar, which is applied and validated once more on the frescos

[10] The same occurs in the Ferroni-Dini method, in which lime is added to frescos in lime, so that it does not modify its chemical structure, as it would happen with the alternative treatment with polymeric resins.

of the Brancacci Chapel, and later on other masterpieces; this method is meant to improve the in-depth consolidation of colours on the wall paintings. In those same years, the new paradigm of nanosciences is establishing itself, and the Florentine group is testing other potential applications to restoration that will turn of fundamental importance in the years to come.

5) Fifth innovation. Nanotechnologies applied to restoration: nano-lime

This innovation marks a significant turning point in the activity of the group, which from now will devote, next to the tradition activities, to the application of nanoparticles to chemical restoration. Nano-lime represents the bridge between the knowledge built by the group of founder scientists and the new generation of scholars. The innovation consists in the application of nanosciences and colloid systems to the Ferroni-Dini method. In this particular field, the Ferroni group will benefit from some world recognised international relationships, such as from professor Pierre-Gilles de Gennes, Nobel Prize for Physics (1990).

Thanks to the work of Giorgi, under the supervision of Ferroni, Dei and Baglioni, it was possible to synthesise nanoparticles of lime for the restoration of art heritage. This innovation had a great impact and was tested, in modified and adapted versions, to a wide range of cultural works. In fact, it served the restoration of paintings not only on walls, but also on paper, wood and other cellulose materials. The outcomes proved to be substantial, so that soon the innovation was patented (Baglioni et al., 1996) and later introduced in industrial production through a collaboration agreement with one of the main distributors of products and equipment for the restoration of cultural heritage, CTS. So, since 2006 the Department of Chemistry has been producing *Nano Restore©*, which is distributed by the company all over the world, also thanks to the close ties the University keeps with Dr. Borgioli, technical manager of the company and former student of professor Baglioni[11].

6) Sixth innovation. "Revised" microemulsions and the Guasconi Chapel in Arezzo

Thanks to the new nanotechnologies, the same period also saw the improvement and adjustment of micro-emulsions. They were perfected and their use with wall paintings shifted from the removal of wax to that of various chemical substances,

[11] It must be noted that the product's turnover is rather low, being used only in small quantities on works of art, paintings, etc. and not on a large scale.

such as polymeric resins (Carretti et al., 2005). In the previous years, paintings and frescos had been treated for preservation and consolidation with acrylic and/or vinylic resins that protected them from the deterioration agents (Giorgi et al, 2006). However this treatment, on the one hand prevented the painting from breathing and was particularly difficult to remove, and on the other proved to turn yellow over time to the total detriment the work. These treatments, widely applied during the 1980s, were then removed thanks to the use of micro-emulsions which fought polymeric resins. This new development was basically an implementation of the operation of wax removal from the Brancacci Chapel frescos, thus an incremental innovation that can be comprised in the new paradigm of compatible restoration, which is directed to use on paintings compatible components instead of chemically unrelated ones (like resins)[12].

A successful application of this restoration method was made on the frescos of the Sala dei Battuti (Hall of the Flagellants) of the Conegliano Cathedral. From then on, the commitment to work abroad at churches as well as monuments intensifies, and the foreign assignments, in Mexico for example, met a worldwide success (Giorgi et al., 2006).

7) Seventh innovation. Gel systems, cross-fertilisation from nanotechnologies

The development of innovations in recent years allowed new progresses in the field of chemical research, leading to the application of gel systems to works of art. Gels are becoming one of the fittest instruments for the conservation of art heritage, because they are much versatile, combinable with a lot of cleaning systems, adaptable to many kinds of applications, and particularly compatible with the work of art (Baglioni et al., 2009). They constitute a methodology with good development and – apparently – business prospects. Besides, the method has already been tested on various kinds of materials (Baglioni et al., 2012).

Finally, although this study of innovation processes is focused on the chemical applications to frescos, it should be recalled that chemical innovations have also been successfully applied to many other materials, such as wood (Giorgi et al., 2006),

[12] Originally, a common opinion in reversible restoration was that the application of resins was the best solution, being reversible, but after various decades it showed to be particularly persistent and its removal sometimes impossible. On this issue see Oddy and Carrol (1999).

canvas, marble, strong stone and travertine (Baglioni et al., 2003), books and paper, and so on[13].

Figure 1 sums up the main aspects of the progress in chemical innovations. The ones we have described so far contributed to the development of a new innovative trajectory that has been very prolific in all the decades under consideration and allowed to establish a new disciplinary niche of Chemistry in Conservation Science (for the restoration of cultural assets). They are all lateral and transversal innovations, developed from cross-fertilisation processes. In fact, innovations such as Tributilphosphate and micro-emulsions are compounds that were originally applied to other sectors (nuclear chemistry and oil recovery). In addition, although they were generated from a problem-solving activity, later they were all implemented, especially thanks to the advancement of physical chemistry. In fact, even if the first improvements, like the Tributilphosphate or the Ferroni-Dini method, were to solve a specific problem, the subsequent innovations, like nano-lime or gels, were the technological implementation of colloids and nanotechnologies in chemistry.

Their achievements were also favoured by the historical and artistic value of the works of art under restoration, involving eminent artists like Taddeo Gaddi, Beato Angelico, Filippo Lippi, etc. and kept in remarkable locations, like the Santa Croce Church, the Saint Mark’s Convent and the Brancacci Chapel in Firenze.

The innovative trajectory has also contributed to a radical change in the approach to heritage restoration. In fact, professor Ferroni’s research group work positions itself first of all in the new approach of modern conservation sciences, a more structured and methodological approach that little by little acknowledged the contributions from other scientific disciplines. Moreover the approach peculiar to all the Ferroni group was to draw attention to the treatment’s compatibility, and consequently on the search and use of components and methodologies as much compatible as possible with the chemical-physical structure of the work (as opposed to reversible restoration, that will be more and more criticised)[14]. All the innovations developed seek compatibility with the work of art, starting from the Ferroni-Dini method and ending with nano-lime and gels.

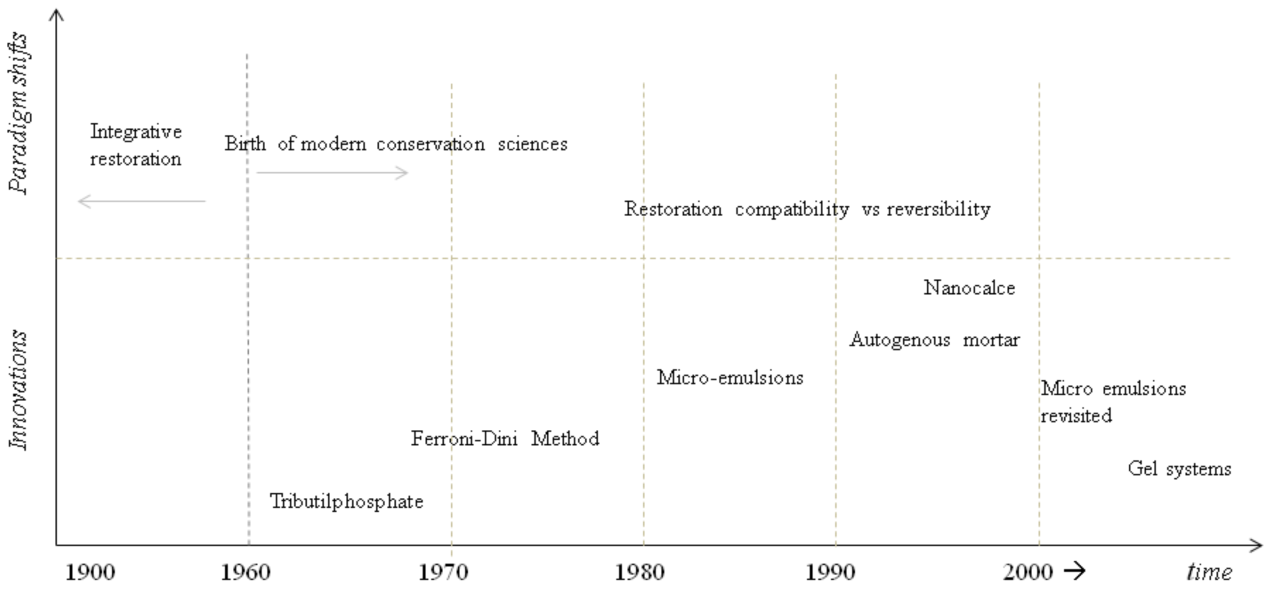
The development trajectory engenders a set of innovations more and more technologically advanced, which add up to a better restoration of cultural assets, but

[13] The success of the research group has grown over time, as showed by the 23 macro-projects at national and international levels financed in the period 2000-2012.

[14] See for example the application of micro-emulsions for the removal of resins during the 1990s.

also modify and improve the approach itself to restoration, in humanistic and in scientific disciplines alike.

Fig. 1 – The new innovative trajectory in Chemistry in Conservation Sciences



Source: our elaboration.

4.2. The scientific innovation network: a bibliometric analysis (1992-2014)

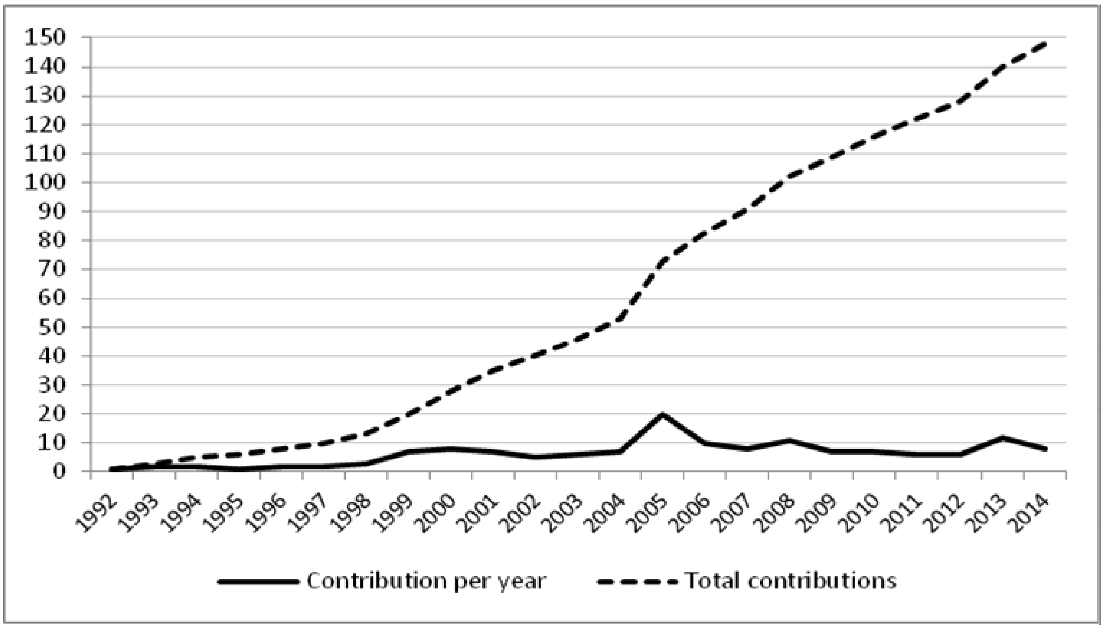
This first investigation on innovators is mainly intended to confirm that the innovations under exams were actually developed by the group of scientists located in Florence, who had a part in building a new trajectory within a specific niche, represented by the modern conservation sciences. Secondly, we wanted to analyse the network's internal organisation and evaluate the degree of connectedness attained as well as identify the actors who play a central and bridging role with other groups/disciplines.

To analyse the scientific community of chemistry in Conservation Sciences, we selected from the database of the CSGI the main publications on the issue from 1992 to 2014. We found more than 148 contributions, involving 125 authors who had made more than 500 interventions each[15]. The resulting curve trend is illustrated in figure 2, which shows a steady increase of publications from the 1990s until it reaches about 150 contributions and an average of about 10 units per year.

[15] The works were selected with the collaboration of experts in chemistry for restoration. The typologies taken into account were monographs, books' chapters and international articles.

These works are mainly addressed to the international scientific community, as it can be inferred from the surveyed publications, which are mostly articles and book's chapters, and for the 76 per cent of cases were written in English. The more prevailing authors are students of professor Ferroni; in particular, we can mentions professors Baglioni, Dei and Giorgi, while the founder has no first position as it might be expected, since he died in 2007[16]. Among the authors' affiliation, beyond the Florence group we find a variety of cases, mostly researchers and restorers referring to CSGI.

Fig. 2 – The evolution of literature in Chemistry in Conservation Sciences (1992-2014)



Source: our elaboration on CSGI database.

What already emerges from these first descriptive analyses is the pre-eminence of the group of Florence's scientists, and the confirmation of the fundamental role it had in the birth and progress of Chemistry in conservation sciences.

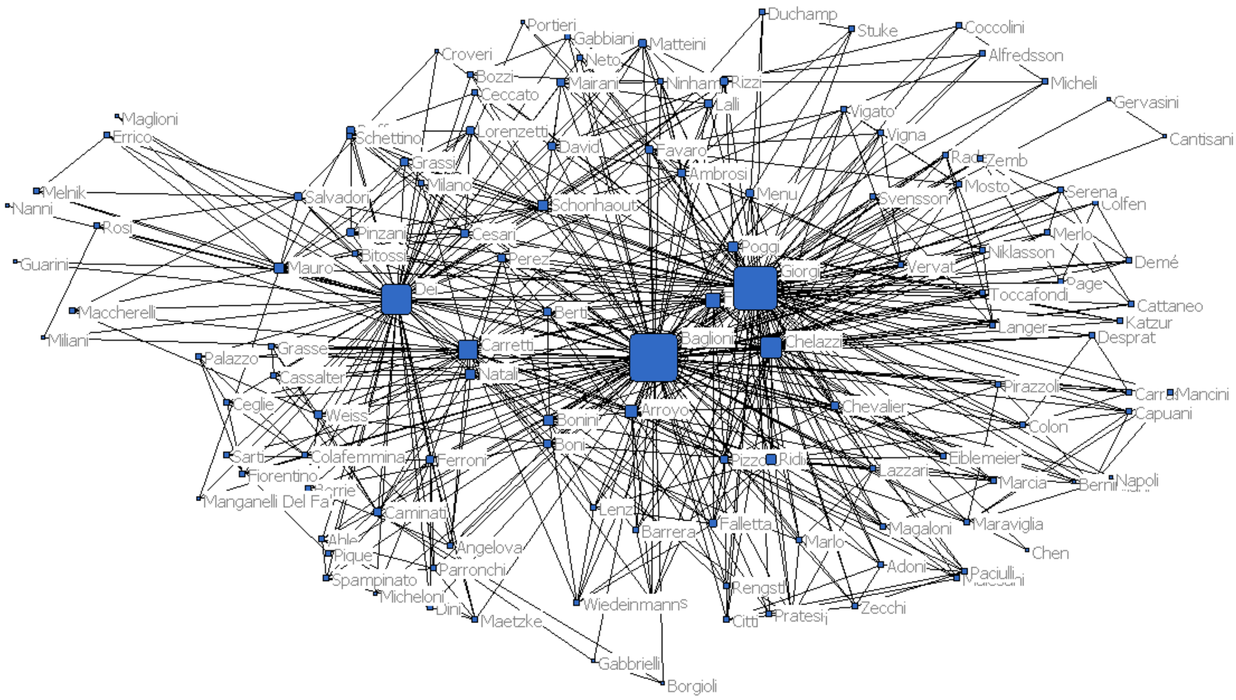
As to the exam of the internal dynamics of scientific relationships, we applied to the authors a SNA of data. The innovation network appears to be very close and united at both the centre and the periphery (fig. 3), which signals the high connectedness typical of scientific communities. It is possible to identify only a few central knots of relationships, represented by a small group of authors, who are much connected one to the other. They are the Ferroni's research group, whose

[16] However, professor Ferroni has a stronger influence if we consider only the national publications. His role in the network is certainly underestimated because his death took place in the period under exam (2007).

recurrences, together with the most central actors, cover almost a 70 per cent of publications[17].

The relevance of professor Ferroni's group, whose members we interviewed (Baglioni, Giorgi and Dei), together with the other Florentine university teachers from CSGI, is confirmed[18]. At the periphery of the graph, we find authors from other Italian regions and foreign researchers, among them Weiss, Arroyo and Ninham

Fig. 3 – The network of actors in the chemistry community resulting from literature on cultural heritage (at least one co-authorship)



Source: our elaboration.

This first analysis reveals that, all considered, Florence hosts a network of scientists very united and interconnected at national and international levels, which can be said to be the leading centre of the innovations under study. The key actors are in fact just the researchers belonging to the group of professor Ferroni, which over time managed to establish itself internationally. Innovations were in fact implemented within this scientific community and with a high degree of international connectedness, which demonstrates the relevance of the actors taking part in it.

[17] We recall that the overall contributions are 148 and the authors' participations under exam are 500.
[18] Among the most prominent professors, we recall Carretti, Chelazzi, Fratini, Mauro, Poggi and still others.

Over time, the group of main actors has also gradually constituted a new disciplinary niche, of Chemistry in Conservation Sciences, and asserted itself as a major point of reference in this field of studies.

Finally, this scientific community has been undoubtedly favoured by the context in which it operates, that is a territory with a rich endowment of artistic and cultural heritage of international significance, and where is located a cluster of art restoration relating to firms, universities and research centres, cultural institutions and local bodies, which contribute together to the activity of preservation and enhancement of the local cultural and art heritage.

5. Final remarks

We would like to remind that this paper was meant to contribute to the still under-researched debate on resilience and innovation, combining the resilience approach with the creative one, and developing the idea of a creative and resilient city starting from the study of the chemical innovations applied to restoration, developed in Florence after the 1966 flood.

The main research questions we intended to answer were:

– Which are the innovations in Chemistry in Conservation sciences developed after the 1966 flood and who are the leading innovative actors?
– Which theoretical implications are behind these outcomes, in terms of relations between resilience and innovation, and ultimately for the design of a "creative and resilient cities"?

The innovations and the innovators who created them seem to generally confirm our assumptions, as they certainly constitute a good example of transversal advancements stemming from cross-fertilisation, produced after an external shock, and stimulated by resilient and lateral thinking. The new trajectory of chemistry restoration was born in the context of a new scientific niche, the modern conservation sciences, which it later contributed to advance, making of the Florentine school a case of worldwide excellence from both a scientific and a humanistic point of view.

In retracing the history of these innovations, the most visible result is that a series of problem solving activities gave rise to new opportunities. This was possible thanks to the application of creative later thinking that led to innovative solutions from a cross-fertilisation of neighbouring sectors, which managed to exploit the diversity and variety of different kinds of knowledge. If it is true that the external shock, on the one hand gave rise to the urgency conditions that compelled the new methodologies, on the other it also created those conditions of discontinuity necessary to the fill the gap with a change of paradigms

As to the innovators, they gave rise to an innovative scientific network mainly composed of scientists, most of whom were students of the pioneer, professor Ferroni. They represent today the core and main bridging actors of a highly-connected network at both national and international levels. This network also represents a strong element of the local system, increasing its connectedness and his creative adaptive capacity after a shock. Such connectedness is further enhanced by the fact that the network belongs to a larger technological cluster for restoration of cultural heritage based in Florence, which comprises the use of laser technologies for restoration and the new ICT technologies (Lazzeretti et al., 2011).

The success of these innovations – and innovators – was also partly due to the city’s renowned art heritage, which has been not only the source of the problems to be solved, but also the object of experimentation, i.e. important work of arts, some of which belonging to the World Heritage (Tab 1).

As regards the possible implications of this study, we believe it supports at least the theoretical argument on the opportunity to follow an integrated approach centred on resilience and creativity which is yet to be analysed.

Some of the concepts developed by the EEG scholars’ analysis of resilience can be very useful in the interpretation of the phenomenon under study. In fact, the first innovations born after the Florence flood can be traced back to the phase of restructuring-reorganisation, and exploitation and growth of the adaptive cycle. Similarly, the typology of these innovations can be usefully interpreted following the theoretical constructs of both EEG and the creative approach. They are transversal innovations derived from cross-fertilisation and path dependence, and ascribable to the creative adaptive capacity of the city after the shock.

This case study also unveils the strategic role of networks in innovative processes, particularly of a network embedded in a city of art and operating within the larger technological cluster for restoration of cultural heritage. In this sort of contexts it is easier to develop an open innovation drawing from the virtuous encounter of resilient and creative thinking. The problem solving activity, generated after an external shock, finds in lateral thinking processes not only the adaptive capacity (creative adaptive capacity), but also the opportunity to recognise forms of unusual relatedness to develop ideas and innovations (for example, nuclear or petrol chemistry applied to cultural assets). This exchange is favoured by a high degree of connectivity between the actors of the network and those of the cluster it belongs to, making possible to build a new innovative trajectory which looks at the city as a creative and resilient *milieu*.

The most recurring question to ponder is why all this happened in Florence and not elsewhere. Well, the answer we give cannot merely lay in the catastrophic event (i.e., the *incipit*), or in the ruin of a notable historical and art heritage (i.e., the problem-solving activity). There is also a third relevant factor in the birth of these innovations, pertinent to what geographers of innovation call path dependence, i.e what is associated with the city's history and its ability to combine the embedded humanistic and scientific knowledge.

Starting from these first conclusions, we think this sort of analyses can be helpful to widen the debate on creative cities and include the plausibility of considering them resilient cities all the while. The studies of resilience can also lead us to take into account a new function of history and art heritage in the examination of the economic and social enhancement of culture. In fact, if heritage is at first considered as an asset to preserve, nowadays it is no more only a source of local economic development and innovation, but also a source of resilience with which to face the risk of globalisation and environmental change.

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