Reducing the Flood Risk of Art Cities: The Case of Florence

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Protecting World Heritage Cities from Flooding

Safeguarding cultural heritage is considered a top priority of modern society. Cultural heritage may be defined as the legacy that is inherited from previous generations. It may be maintained in the present by means of tangible features (such as buildings, monuments, landscapes, books, works of art, and artifacts) or intangible culture (such as folklore, traditions, language, and knowledge). This forum article describes the pressing need to reduce the flood risk facing the city of Florence (Firenze in Italian) to safeguard vulnerable persons and preserve its remarkable cultural heritage. Many other art cities in Europe (such as, for instance, Budapest, Paris, and Vienna) face similar risks from floods.

Historical cities in Europe embody an inestimable treasure of cultural heritage for their art collections, buildings, urban organization, and traditions. They also are an example of endured urban sustainability despite dramatic societal, climatic, and environmental changes that have occurred over the centuries. Notwithstanding their proven resilience, historical cities now are threatened by natural and human-induced hazards such as climate change, earthquakes, air pollution and traffic and, above all, floods. Many historical cities were built along the courses of important rivers, and therefore they always have been prone to flood hazard. However, the flood risk is today increasing at an unprecedented pace because of rapid urbanization and climate change. Furthermore, funding restrictions and new approaches to the conservation of cultural heritage and the environment today make the setting up of efficient risk mitigation actions more complicated and lengthy than in the past.

The European Council recognizes the great cultural, environmental, social, and economic value of cultural heritage. Its protection is guaranteed by the Treaty of European Union (TEU), Article 3.3 [2007/C 306/01 (December 13, 2007)], according to which the Union "shall respect its rich cultural and linguistic diversity, and shall ensure that Europe's cultural heritage is safeguarded and enhanced," and the EU Charter of Fundamental Rights, Article 22 [2000/C 326/02 (December 7, 2000)], according to which the Union "shall respect cultural, religious and linguistic diversity"; the Charter is binding on the EU institutions and on national governments. The Treaty on the Functioning of the European Union (TFEU) [2012/C 326/01 (October 26, 2012)] enumerates Union actions (Article 167, Point 2) to improve cooperation between the Member States, which include conservation and safeguarding of cultural heritage of European significance.

The EU Floods Directive (FD) [Directive 2007/60/EC (October 23, 2007)] seeks to reduce adverse consequences of floods, including their impacts on cultural heritage (Directive 2007/60/EC, Article 1), through flood management plans. The TFEU specifies conservation of cultural heritage as one of the cases in which state aid may be compatible with the internal market regulation.

Despite the aforementioned recognition and policies, the exposure of European cities to floods still is unsustainable, as recent floods (e.g., the 2013 flood in central Europe and the 2014 floods in the Balkans) have clearly shown (Hall et al. 2014). Therefore, the development of a framework of actions for safeguarding European cultural heritage from floods is an urgent societal priority. In this regard, hydraulic engineers and researchers can assist both by extending the current body of knowledge regarding flood risk and by identifying actions that need to be taken to reduce such risk in historical cities.

In recognition of the urgent need of enhancing the resilience of cities of art to the effects of natural catastrophes, the President of the Accademia Nazionale dei Lincei (Accademia Nazionale dei Lincei and InterAcademy Parternship 2016) and the Co-Chair for Science of the InterAcademy Partnership (Accademia Nazionale dei Lincei and InterAcademy Parternship 2016) signed the Charter of Rome on the Resilience of Art Cities to Natural Catastrophes (Accademia Nazionale dei Lincei and InterAcademy Parternship 2016). In addition to emphasizing the value of historical cities and the need for urgent action, the Charter points out that cultural heritage and art cities need to have a special status when developing plans for reducing the impacts of natural disasters. The Charter also

aims at informing politicians of their responsibilities in this regard and notes that academies also must take on activities such as educating the public and raising awareness, promoting additional research and providing a forum for discussing the results, and providing advice to policy makers in a manner that avoids conflicts of interest.

Floods in Florence

ITSC

The major flood that occurred in the city of Florence in November 1966 was the most catastrophic event in terms of damage to cultural heritage and economic activities that has challenged Florence. It caused 38 deaths in the city of Florence and its province, and destruction of precious works of art, early literature, and archaeological exhibits. It is a cornerstone event in the history of Florence (Nencini 1967).

On the 50th anniversary of the 1966 flood, the Committee Firenze 2016, a regional organization gathered by the University of Florence and later chaired by the mayor of Florence and the President of Tuscany Region, in January 2014 appointed an International Technical and Scientific Committee (ITSC), composed of six engineers and scientists, to assess the current hydraulic risk in Florence of inundation by the Arno River, and identify possible steps that might be taken to reduce this risk.

After three years of activity, in October 2017 the ITSC presented its final report (Galloway et al. 2017) to the Committee Firenze 2016 for further transmission to the local, regional, and national governments. This article summarizes the main findings and recommendations of the ITSC, and more generally provides considerations for protecting art cities from flooding.

Arno Basin, Florence, and Its Structures

The Arno River basin is located in the region of Tuscany within the mountain belt of the Northern Apennines; the overall catchment area is 8,238 km^2 and its average elevation is 353 m above mean sea level. The watershed is subdivided into six subbasins: Casentino (upper valley), where the Arno flows south-eastward; Val di Chiana left tributary (southeast); the upper Valdarno interbasin, where the Arno flows north-westward; the Sieve right tributary (joining the Arno River 18 km upstream of Florence); the middle Valdarno, including the Florence plain; and the lower Valdarno, including the Pisa plain and various tributaries (Fig. 1). In the city of Florence (with a drainage area of about 4,300 km^2), the Arno has a straight channel without a floodplain and passes four weirs (also known as pescaie) and eight bridges connecting the right bank of Florence, where the historical city is located, to the left bank (Fig. 2). The 2-km reach of the Arno in the historical area of Florence, formerly delimited by the outer circle of the city walls, is bounded by two oblique weirs, the San Niccolò and the Santa Rosa; within this reach are four bridges, Ponte Alle Grazie, Ponte Vecchio, Ponte Santa Trinita, and Ponte alla Carraia, which impact the hydrodynamics and morphodynamics of the river, limiting its conveyance capacity [Galloway et al. (2017) and reference therein].

Historical Floods

Floods have been part of the history of Florence at least since the twelfth century. The most catastrophic floods occurred in 1333, 1547, 1557, 1589, 1740, 1758, 1844, and 1966 (Arno River Basin Authority 2017). Interestingly, those of 1333 and 1844 happened on the very same day of the year, the day of the 1966 flood: November 4 (Panattoni and Wallis 1979). The maximum water levels of some of these floods (such as those in 1333, 1557, 1844, and 1966) are documented by stone plaques placed on various buildings, and by maps of the inundated areas (Losacco 1967).

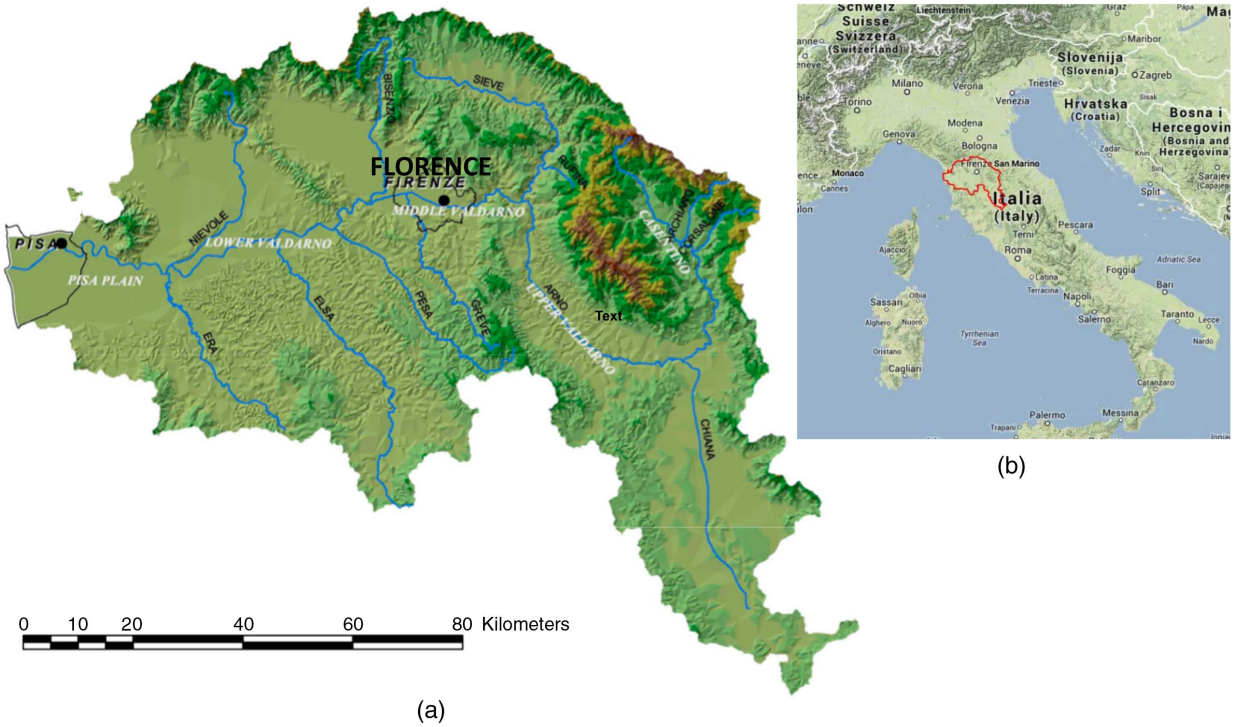

Fig. 1. (a) The Arno River basin with its main tributaries [modified from Caporali et al. (2005), with permission from Associazione Italiana di Geologia Applicata e Ambientale]; and (b) location of the Arno River Basin in Italy [reprinted from Galloway et al. (2017), under Creative Commons-BY-4.0 license].

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Fig. 2. Arno River in Florence and locations of its structures: bridges, weirs (pescaie), and Uffizi gauge station. (Map data © 2013 Google.)

In 1966, on November 3 and 4, several rain gauges located in the Arno River basin recorded more than 200 mm of rainfall in 48 h. Notably, this event followed previous precipitation events in October 1966 which produced a high degree of saturation of the soil in the River Basin. Florence was flooded on the morning of November 4, 1966. The stream initially overtopped the bank protections upstream, and then along the Lungarni, where the banks failed at various sites.

Because the flood destroyed many hydrometric stations together with the recorded charts, flow hydrographs were reconstructed mainly by coupling high water marks with the hydraulic modeling of flood propagation in the river. The peak flow just upstream of Florence was estimated as 4,100 m^3/s, which corresponds to a return period of about 200 years; however, the flood volume was exceptionally high because the discharge exceeded the carrying capacity of the river (estimated to be around 2,500 m^3/s at that time) for more than 20 h. The estimated flood volume that inundated Florence was almost 100 Mm^3 (Principe and Sica 1967) Maximum water depths in the city were in the range 5–6 m and were registered in the historical center and in particular in the area of Santa Croce (Fig. 3). The flood water contained mud, from suspended sediment transport in the river, and naphtha, which at the time was stored in the basement of buildings for heating purposes; this mixture was particularly harmful for art works, which later required highly specialized restoration skills (Batini 1967).

Protection Works: Planning Versus Implementation

Immediately following the 1966 Florence flood, the government of Italy established a committee to assess flood risk over the country, the De Marchi Commission, named for its chair, Professor Giulio De Marchi (Commissione Interministeriale per lo studio della sistemazione idraulica e della difesa del suolo 1969). The Commission's 20-year work introduced a national program of interventions for land protection and led to the enactment in 1989 of a landmark law (Law 183/1989), which moved Italy toward a more integrated approach to soil and water management and the establishment of river basin authorities (Di Giovanni 2016). The De Marchi Commission's efforts also resulted in the initiation of several flood risk-reduction projects in the Arno Basin, but they were never adequately implemented.

Actually, between 1966 and 1996, little action was taken to reduce the flood risk in the Arno Basin. Local flood protection works and policies were proposed, and some were carried out, but they were not part of a comprehensive plan. The only significant intervention was the lowering of the aprons, in 1980, of the Ponte Vecchio and S. Trinita Bridges in the center of the city, which increased the conveyance capacity of the Arno River in the urban reach from 2,500 m^3/s (in 1966) to 3,100 m^3/s (3,400 m^3/s with no safety allowance).

The establishment of the Arno River Basin Authority (AdB) under Law 183 led to the development in 1996 of the Hydraulic Risk Plan (HRP) for the Arno Basin, but cultural heritage did not receive any specific attention in the goals of the HRP. The HRP stated that Florence still would be at risk if the 1966 flood occurred again. The HRP identified the principal causes of this situation: (1) inadequate hydraulic protection works and absence of storage capacity along the river; (2) urbanization of areas formerly used for agricultural purposes; (3) abandonment of forestry and agricultural activities in hilly regions; and (4) insufficient maintenance of hydraulic works and river channels. Accordingly, HRP identified the key elements for a successful flood protection strategy, which included (1) increasing the storage capacity for flood waters in the basin, (2) increasing the conveyance capacity of the river, (3) heightening of the levee system, and (4) improving control of and response to flood events. However, only a few of these measures were implemented, most notably the completion around 2000 of the Bilancino Dam over the Sieve River, which reduced the flood flow in Florence by 100–200 m^3/s.

In 2005, after a modification of the relevant legal framework in Italy, the HRP was replaced by the Hydro-Geological Plan (PAI). The interventions planned by the PAI essentially were the same that were foreseen by the HRP. The PAI devoted some attention to the

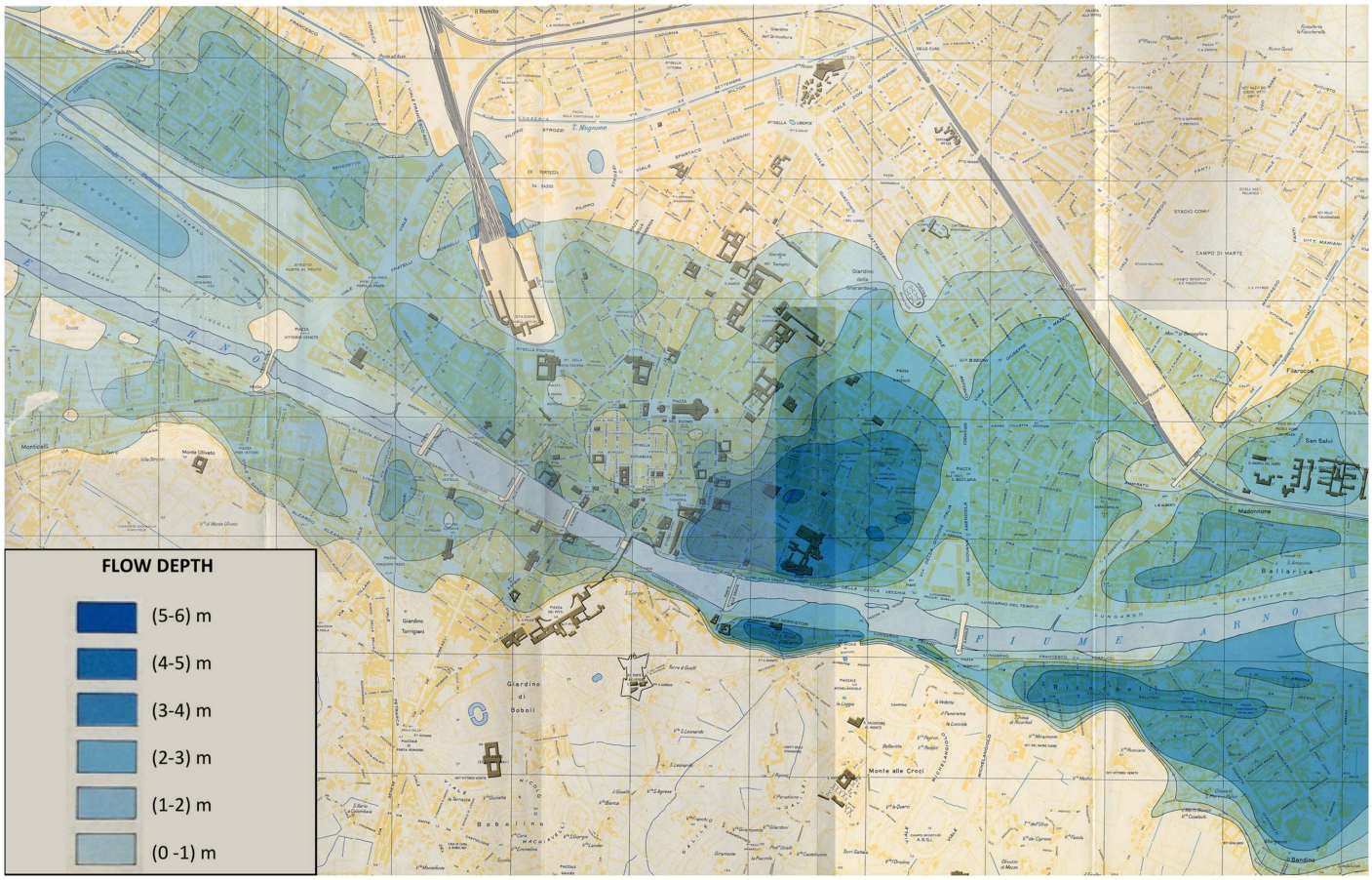

Fig. 3. Flood map during the event of November 4, 1966, with indication of the depth reached by the flooded waters: dark shading = 5–6 m; light shading = 0–1 m. (Reprinted from Principe and Sica, L'Universo, 2, 1967, Anno XLVII, with permission from Istituto Geografico Militare. Reproduction prohibited.)

funding required to implement the measures. The last planning action that was taken to address the flood risk in Florence was the Flood Risk Management Plan (PGRA), approved in 2015, in line with EU Directive 2007/60/CE (the flood directive). The PGRA also was developed by AdB, in cooperation with the National Authority for Civil Protection. The PGRA superseded the PAI, and therefore is the current basis for planning future actions.

The PGRA classifies the measures to be undertaken into four classes, following the flood directive, and discusses extensively the novel philosophy, which may be summarized as from the culture of safety to the culture of risk management, involving cost/benefit analyses and the acceptance of residual and sustainable risks. Cultural heritage now is clearly stated in the PGRA as one of the major assets to be preserved. The plan does not give priority to protection measures with strong impact, such as dams. Solutions mainly consist of flood detention areas of small sizes, with low impact, which do not modify the normal flow regime but act only during the most destructive flood events. The result of this new philosophy is a list of planned interventions on which the protection of Florence will rest: (1) detention areas, (2) heightening of existing dams, and (3) removal of silt deposits from existing dams to recover part of the storage.

The ITSC Review

When, in October 2016, the ITSC presented the results of its study to Progetto Firenze 2016 for further transmission to the governments of Florence, Tuscany, and Italy, it reported that Florence remained at risk to significant flooding, that this risk grew each day, and that it was not a question of whether a flood of the magnitude of 1966 or greater will occur, but when. It found that the level of protection that existed in Florence in 2016 did not yet provide the risk reduction needed for the city and is not on a level appropriate to the citizens and treasures resting within the city. A 1966-like flood, accommodating the limited retention measures implemented since then, still would peak at around 4,000 m^3/s, which is much higher than the current expected conveyance of the Arno in Florence of 3,100 m^3/s, and thus would lead to widespread inundations in the city. The ITSC also reported that if such a flood occurred under 2016 conditions, the consequences to human lives, treasures, other properties, and community infrastructure could be much more catastrophic than they were 50 years earlier.

As described previously, some actions have been taken since 1966 to reduce the risk of flooding. However, these actions have not been sufficient to provide the standards that one would expect for a world cultural heritage city. Because of changes that have occurred throughout the river basin, threats to human lives and property continue to increase. As noted previously, although in 1996 an Arno River Basin Plan was issued which described the actions deemed necessary to deal with the flooding as it was perceived at the time of the plan, the resources to support implementation of the plan have been slow in coming, and, as a result, most of the proposed projects have not been resourced and necessary actions have not been initiated. Some actions that are proceeding are

underfunded. In fact, several of the measures that were planned in 1996 were proposed again in the 2005 Hydro-Geological Plan and once again by the 2016 Management Plan of Flood Risk that was approved by the Arno River Basin Authority in compliance with the European Flood Directive.

Unfortunately, at the current pace of activity and the level of support being provided, ongoing flood risk reduction efforts will not ensure the safety of the city and its cultural heritage for many decades to come. The ITSC believes that, although the citizens of Florence and Tuscany may be aware of potential flooding from the Arno River, they do not have adequate understanding of the magnitude and significance of this flooding. It is critical that national, regional, and local governments work together to communicate these risks to the public and develop an integrated plan to deal with the hydrologic and socioeconomic risks that exist. The protection of Florence is a problem of national and international importance. It also is important for these governments to understand that the time and resources that would be required to recover from the shock of another flood would be much longer and much larger than in the past, and therefore the economic consequences would last longer.

The ITSC recommended that the Italian Government, being aware that the protection of Florence is an issue of national and international relevance, should urge the appropriate institutions (Florence Municipality, Tuscany Region, Water Basin Authority, and National Civil Protection), to prepare, on an accelerated schedule, and submit to the Italian government's attention a comprehensive plan integrating structural and nonstructural measures for the protection of Florence. The plan should be structured to maximize the coordination of the mitigation measures being employed, thereby resolving the current fragmentation among responsible bodies. It should be detailed enough to define the further interventions that are needed, with their feasibility based on a cost-benefit analysis and a realistic time scale for their implementation. The plan also should include a comprehensive assessment of the socioeconomic impact of a flood like the 1966 event on Florence and its cultural heritage.

Given the changing conditions in the basin and advances in engineering, there is need for continuing review of the measures in the latest version of the PGRA. Innovative approaches must be conceived or more fully developed and considered as implementation of the plan or its modifications move forward. The ITSC's review suggests that there is no clear agreement on the target conditions to be achieved as a flood passes through Florence. Should the flow that must be passed without overtopping the banks be based on the peak flow of the 1966 flood or the peak flow for some other flood return period? The ITSC suggests that, given the uncertainties with forecasting precipitation under climate change in relatively small areas with complex orography such as the Arno catchment, and the small changes in the flood probability in this region in the last decades (Blöschl et al. 2019), a flood with a peak and a volume like the 1966 flood would be a logical flood to consider when designing flood management strategies for Florence.

The ITSC recognized that the structural measures previously mentioned represent only one part of the portfolio needed to deal with flooding, and that nonstructural measures also should be part of the portfolio. The use of such measures as land-use planning to reduce future occupancy of higher hazard areas, relocation of nonhistorical structures at greatest risk, early warning systems, flood insurance, and flood-proofing, where they have not already been put into place, should be part of the risk-reduction portfolio and will complement other emergency measures already in place or under consideration.

Fundamental Issues Emerging from Florence Experience

This section briefly outlines the main issues related to risk assessment and protection of cultural heritage.

Planning Priorities and Evaluating Risks

The risk of flooding undergone by the city of Florence was evaluated using the following approach in the PGRA issued in 2016. Firstly, hazardous areas in the Arno basin were identified and mapped. Hydrologic-hydraulic modeling was used to estimate the areas of the city that likely would be inundated with a given recurrence interval along with the water depth in flooded areas. Using this approach, the historical center of the city of Florence was not included among the very high– or high-hazard areas. Furthermore, the flood volumes of the hydrographs considered were much less than that of the 1966 flood, and one would expect more widespread flooding for a 1996-like volume. To proceed from hazard to risk, the areas and values exposed to risk were mapped (e.g., number of human lives, economic value of goods). No special status was assigned to urban settlements where enormous cultural heritage was present. The outcome of this procedure was a risk map in which risk was classified into four classes of increasing risk, from R1 to R4 (Fig. 4). This map suggests that the risk faced by suburbs of Florence such as Scandicci and Lastra a Signa would be higher than the risk faced by the historical center of Florence. One can hardly reconcile this conclusion with common sense and with the statement in the PGRA that, in spite of the estimated moderate hazard of the Florence center, the associated risk would be quite high due to the "incommensurable artistic and cultural value" of the city of Florence.

A major paradoxical consequence follows from the above risk map. Any structural intervention in the city of Florence, even the lowering of the apron of the Santa Trinita Bridge realized after the 1966 flood, would be rejected nowadays on the grounds that reducing the risk of flooding in Florence would increase the risk downstream. This state of affairs raises a major issue: What is the economic value of cultural heritage? To what extent could (or should) this value be accounted for to establish priorities concerning the measures planned to reduce the risk of flooding in art cities? Efforts in this direction, along the lines of recent research in the field of environmental economy (Serageldin 2016), are urgently needed to support a broader perspective of flood risk management that puts the risks into a regional perspective rather than a narrow local view.

Emergency Plans and Cultural Heritage

A second related issue arises as a consequence of the insufficient action undertaken by the national and regional institutions in the last 50 years. Because no drastic changes seem foreseeable for the near future, the availability of emergency plans becomes crucial.

Although the effectiveness of the Italian Civil Protection system in both flood forecasting and postevent recovery has definitely improved with respect to 1966, the loss of lives caused by a catastrophic flood likely would be much larger than in 1966. Indeed, today a much larger number of people live in basements throughout the historical center, and the population of tourists has increased significantly in the last 50 years. The timely activation of protocols recently set up may mitigate the impact of a flood on only a small number of the cultural assets. Speaking in Rome at an International Conference on Resilience of Art Cities to Natural Catastrophes, Acidini (2016) noted that

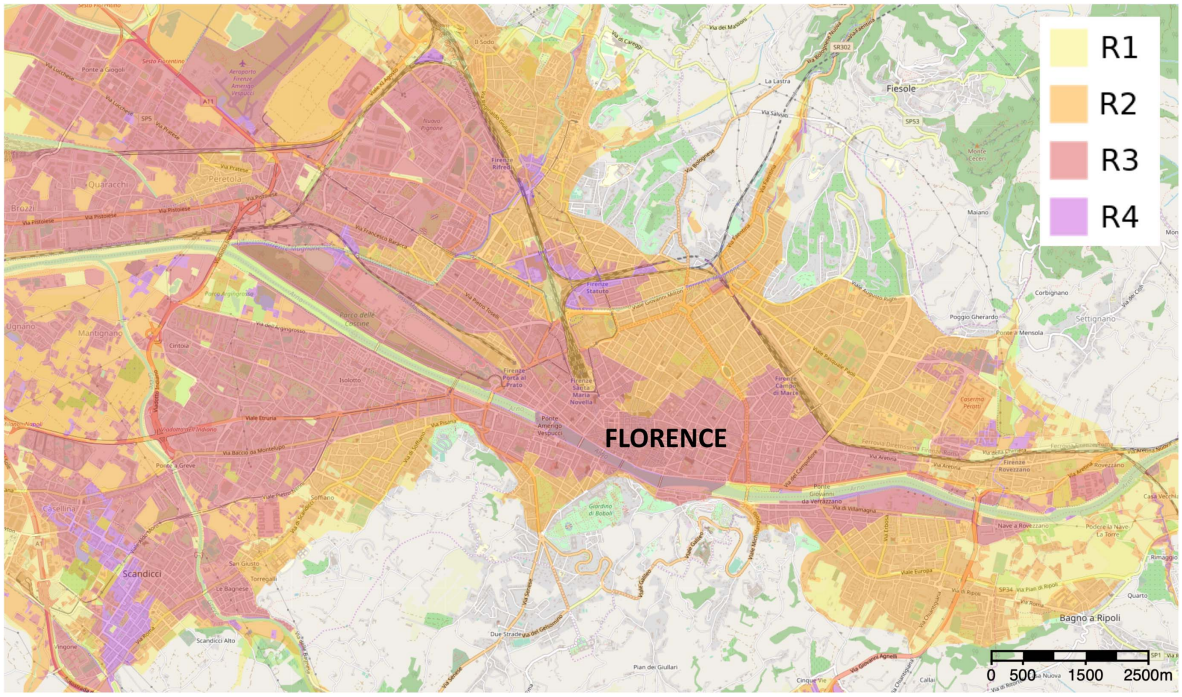

Fig. 4. Risk Map of the Florence Area. [Data from Arno River Basin Authority (2017); map data © OpenStreetMap contributors, reproduced under Creative Commons-BY-SA 2.0 license.]

> if many of the works of art ... once restored have been located exactly where they were previously, this happened, not for a misguided optimism, but also and above all for the impossibility of doing otherwise. The monumental religious and centuries-old buildings obviously cannot but remain in their places, the frescoes ... cannot be moved from their original locations, the altarpieces have been reassembled onto their altars, which have a predetermined—and not modifiable—spatial relationship with the floor. The risk, therefore, ... persists in the same places for the majority of the works of art relocated back in place.

The conclusion implied is that until adequate structural interventions are completed, Florence can be saved from a possibly worse repeat of 1966 only if the emergency plan includes actions to move the negative consequences of a catastrophic flood upstream of Florence, to less densely populated areas with lower economic and cultural value. This plan obviously should include appropriate economic incentives, insurance support, and evacuation plans for the population involved. Although this is not an easy task, it very certainly is worth pursuing. This state of affairs has prompted the ITSC to more generally urge the relevant authorities in Europe to take the protection of cultural heritage guaranteed by the EU Treaty (Article 3.3), the EU Charter of Fundamental Rights (Article 22), and Article 1 of the Eu Floods Directive (2007/60/EC) fully on board. Although these documents are clear about the need to protect cultural heritage, they do not outline the funding strategy required to implement this need. This disconnect results in a dilemma that is seen clearly in Florence and other cities of arts in Europe, where everyone seems to agree in principle on protective actions, yet the resources to support them are slow in coming, and, as a result, many of the proposed projects have not been resourced. Such a plight also is faced by the USACE.

Historical cities in Europe embody an inestimable treasure of cultural heritage for their art collections, buildings, urban organization, and traditions, and preserving them for the generations to come is a most urgent need.

Afterthought

Few people know that Leonardo da Vinci and Niccolo Machiavelli worked together during the first decade of the sixteenth century, driven by the inspiration of one of Leonardo's most fantastic dreams: to build a system of canals that would make the Arno River navigable from Florence to the sea. As described by Masters (1998), the first canal had a military purpose: to cut off the water supply of Pisa, Florence's enemy at the time. However, Leonardo dreamed of irrigating the Arno valley and controlling its water in order to fill Florence's coffers with tax revenues. He and Machiavelli foresaw a day when Amerigo Vespucci and other explorers would be able to sail from the city center to the sea, to travel to new lands and enrich Florentine merchants. Unfortunately, a flood destroyed the Pisa diversion canal during its construction and the project was abandoned. Had the taming of the Arno succeeded, Florence might have become the center of a great world power. Instead, Florence flourished in other unexpected ways and became a world center for the arts, with a unique cultural heritage which needs protection from the Arno's floods. "Fortune is a river" (Masters 1998).

Data Availability Statement

No data, models, or code were generated or used during the study.

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