Landscape design in infrastructure projects - is it an extravagance? A cost-benefit investigation of practices in dams

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Highlights:

- Global practice of dam design was investigated for landscape or architectural design features and 53 cases were identified
- Landscape quality perception improves in such cases, as manifested by literature and photograph uploads
- Through three case studies it was demonstrated that low costs and technical requirements are feasible for landscape design of infrastructure works

Keywords:
Civil infrastructure, landscape design, architectural design, dams, feasibility, project cost, landscape value perception, geotagged photography data bases, google maps, landscape planning policy.

Abstract: Landscape design of major civil infrastructure projects has often been undermined as a policy requirement or been neglected in practice. We investigate whether this is justified by technical challenges, high costs or proven lack of utility of landscape design of infrastructure, focusing on dam-design practice. Initially, we investigate global practice and identify 56 cases of dams in which landscape or architectural works have been carried out. We then create a typology of utilized design techniques and investigate their contribution to improving landscape quality perception through literature review and through the analysis of photograph upload densities in geotagged photography databases. Finally, we investigate costs of landscape works, analysing three dam projects in detail. The results demonstrate that landscape design of civil infrastructure (a) improves landscape quality perception of infrastructures' landscapes and (b) that its implementation can be both economically and technically feasible, especially if existing knowledge from best practices is utilized.

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1 Introduction

1.1 The question of landscape design of major civil infrastructure

In the last decade, the advancement of the architectural and landscape design of major civil infrastructure has been identified as a crucial focus-point for the future research agenda of landscape architecture (Ioannidis, 2022; Meijering et al., 2015; Nijhuis et al., 2015). The major role that the so called "landscape impacts" have had in the discussion over the sustainability of the renewable energy transition (Ioannidis & Koutsoyiannis, 2020; Jefferson, 2018; Pasqualetti, 2011) has certainly contributed to this regard.

However, so far and in most countries, architectural and landscape design studies are still not required for major projects of civil infrastructure such as dams, bridges, highway networks and solar or wind energy projects and (Kara et al., 2017). Overall, when it comes to major civil infrastructure project, the landscape design sector is generally considered to be underdeveloped both in practice (Fischer et al., 2000; Moosavi et al., 2016) and in academic research (Vicenzotti et al., 2016). The few cases worldwide in which landscape design has been consistently and widely implemented during the development of infrastructure are limited to some of the countries with highly developed economies[1], where landscape design requirements are included in institutional design standards, e.g. in countries in Europe and in the USA (Chugh, 2011; Thompson et al., 2006). It has to be noted though that in practice, even in those countries, the implementation of landscape design is in many instances limited to peripheral interventions such as slope restorations and planting trees, without intervening in the shape and surface of infrastructure.

Hence, the primary research question of this study is whether landscape design can have a more important role in the design process of infrastructure. To this aim, we focus on the following two issues that we perceive as most essential for decision makers in matters of design and planning policy: (a) the investigation of the utility of landscape design in works of civil infrastructure and (b) the investigation of the potential for its wider implementation with emphasis on the examination of cost-associated or technical limitations. According to the results of these investigations the academic community could potentially argue for a more important role for landscape design of infrastructure, to technical and political authorities that shape relevant policy.

1.2 Dams as the focus of the study

The decision to focus on a particular type of infrastructure was made so that the investigation of the general research questions of the study can be predominantly practice-oriented rather than theoretical. This point was considered necessary for the in-depth investigation of the research questions of the study regarding the utility and feasibility of landscape design in major civil infrastructure projects.

Dams are arguably some of the most crucial works of infrastructure (Koutsoyiannis, 2011; Nikolopoulos et al., 2018) and are multipurpose projects that are used for water supply, irrigation, energy generation, flood protection and other purposes (Dimas et al., 2017; Efstratiadis & Hadjibiros, 2011; Sargentis, Ioannidis, et al., 2019; Sargentis et al., 2020). They were identified as a suitable focus for the investigation of landscape design practice in infrastructure, due to the fact that various cases can be found in which landscape design has been utilized and positively perceived landscape transformations have been generated[2] (Fleetwood, 2010; Frolova, Jiménez-Olivencia, et al., 2015; Ioannidis & Koutsoyiannis,

[1] We use the term as it is defined in the UN classification (United Nations Department for Economic and Social Affairs, 2019)

[2] The definition for landscape that is followed in this study is the definition of the European Landscape Convention (https://www.coe.int/en/web/landscape/the-european-landscape-convention) that

2017b; Kreuzer, 2011; Nynäs, 2013); but also various cases in which no landscape or architectural treatment has been applied are also observed. Thus, through the focus on landscape design practice in dams, interesting comparisons can be made and the general research questions of the study can be partitioned into these more specific and quantifiable research questions: Has landscape and architectural design been implemented successfully in dams? At what cost? Can it be demonstrated that it has contributed to increasing the sustainability of the generated landscape changes (especially in comparison to cases in which it has not been applied)? And if that is the case, is the wider realization of landscape design in this type of projects technically and economically feasible?

In terms of the scale of the analysis, the investigation for the feasibility and typology of landscape practice in dams is carried out on a global scale, examining cases of landscape design implementations from more than 20 countries. On the contrary, the examination of projects' budgets is approached through a more targeted and detailed analysis of three projects. It is also noted in this regard, that so far the architectural potential of dams has largely been left untapped and landscape design has only been utilized sporadically (Ioannidis & Koutsoyiannis, 2017b). Therefore, the investigation of landscape-design practices in dam projects was carried out globally, so that a sufficient number of cases of dams could be collected and analysed. This challenge led on the one hand to the inclusion of dams from all six inhabited continents in the study, while on the other hand, it further demonstrated how landscape design has been neglected in major civil infrastructure projects. Notably, given that dams have been recipients of criticism over various social and environmental impacts (Mamassis et al., 2021), it would be reasonable to expect the implementation of any available measure to mitigate them, including landscape design, would have been supported more.

2 Methods

2.1 Study structure

In section 2.2, we briefly describe the setup of dam projects and the basic components of dams. In section 2.3, we analyse landscape-design practice in dams and formulate a typology of architectural and landscape design implementations. In section 2.4, we investigate how the utilization of the designs of the typology of section 2.3 has affected the perception of the public on transformed landscapes. This is carried out through the analysis of photograph uploads in the proximity of dams in geotagged photography databases (in Greece) and through literature review (Globally). Finally, in section 2.5, we investigate the project-cost requirements for the implementation of landscape design studies through the analysis of the budgets of two realized projects as well as the budget of a theoretical case study specifically formulated for the purposes of this study.

2.2 Dam projects' setup

References to dam design in this study will be limited to the basic setup of a dam's site and to its primary structural parts (Figure 1). The body of a dam is the main structure that blockades water and creates an artificial lake or reservoir. It has three main parts: the downstream face that is visible in Figure 1, the upstream face, which fronts onto the reservoir, and finally, the dam-crest. Reference will also be made to appurtenant structures and to the peripheral landscape of dams. With the term "peripheral landscape" we define the broader reservoir area including the natural terrain surrounding the structural parts of dams; this is the area that commonly requires restoration after the construction of dams. In relation to the appurtenant structures of dams, reference will be made to (i) spillways and outlet works that are used to

"landscape is part of the land, as perceived by local people or visitors, which evolves through time as a result of being acted upon by natural forces and human beings".

channel or siphon, respectively, excess water downstream of the dam when the reservoir reaches its full capacity (Koskinas et al., 2019) (ii) powerhouses that are the buildings where energy generation and conversion equipment is installed, in the case of hydroelectric dams, and finally (iii) valve towers that provide access to valves for the control of outlet works.

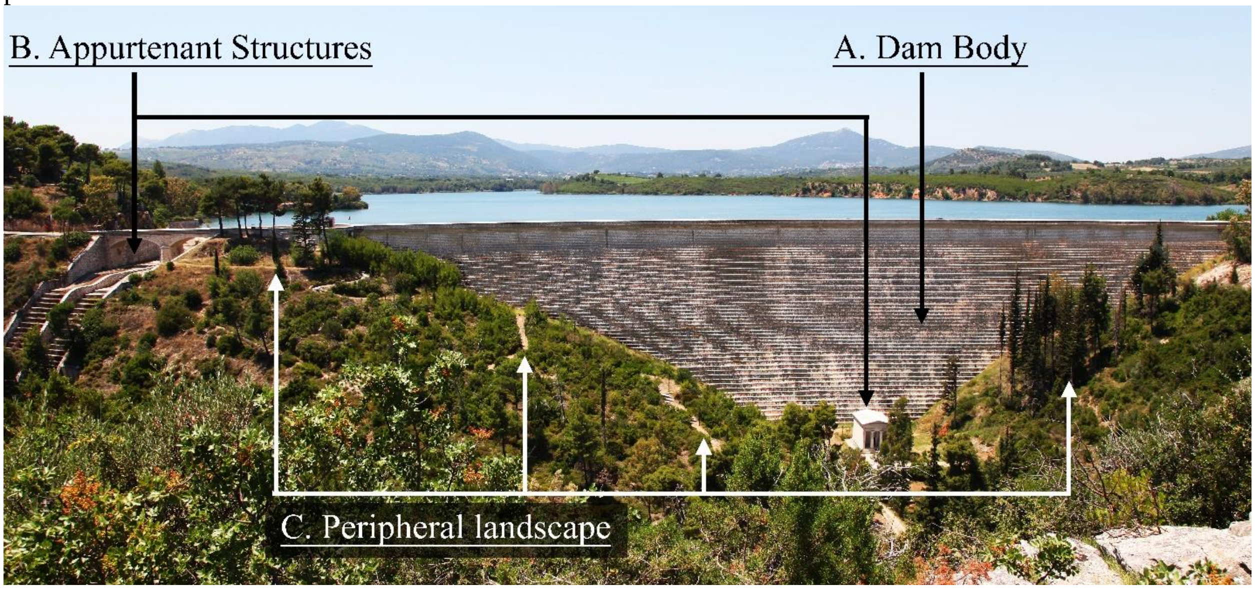


Figure 1 A dam's project-site: (A) Dam body, (B) Appurtenant structures (Spillway and reservoir control facility in this case) and (C) Peripheral landscape (planted with trees and redesigned with walking trails in this case). The dam presented in this figure is the Marathon dam in Greece.

2.3 Practice of landscape design in dams

Dams, similarly to all works of engineering, have inherent aesthetic qualities regardless of whether they have had architectural treatment or not. The majority of dams globally are in fact formed solely as the result of their technical requirements, meaning that architectural and landscape concerns have no role in the design process. The focus of this study however is not on these cases of dams; we rather focus on the cases where additional design elements have been specifically implemented in order to better integrate the dam into landscapes or to enhance its aesthetics[3]. Thus, in this section, we collected cases of dams that included architectural and landscape design features, from global practice, aiming (i) to investigate the feasibility of landscape and architectural design in dams, as demonstrated in realized projects, and (ii) to create a typology of designs that can be used later in the study for the assessment of the contribution of landscape design to improving landscape quality perception.

2.3.1 Collection of data

For the collection of data from landscape-design practice in dams, searches were initially carried out in academic and institutional literature. However, since literature in this field was not very extensive and was either focused on individual case studies (Kreuzer, 2011) or on single countries (Fleetwood, 2010; Nynäs, 2013), data searches were also carried out in web search engines. The searches were directed to data from websites of institutions and organizations that are active on the fields of dam design, hydropower and cultural heritage. The keywords "dam landscape design in (country name)" and "dam

[3] The only exception to this is our reference to arch and buttress dams, because their highly perceived aesthetics have already been correlated to their inherent geometrical characteristics in literature, as explained in more detail in section 2.3.2.

architecture (country name)" were used followed by searches using the same keywords translated into the respective official languages of various countries using Google translate. The countries that were included in the searches were, firstly, the top 10 countries globally, ranked by number of dams[4], and secondly, various other countries that were identified by the authors as potentially relevant, based on their personal experience, such as: The United Kingdom, Norway, Switzerland, Greece, Australia, France, Egypt, Algeria, Germany, Italy, Turkey, New Zealand and others.

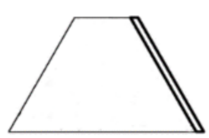
Other than the text of the examined literature and websites, dam-photographs included in these sources were also investigated. Since dams do not have publicly accessible interior spaces, architectural and landscape design features are by default visible on the exterior of dams and their appurtenant structures. Thus, landscape design features of dams were identified both from the examination of literature and from photographs of dams. For the latter, the experience of the authors on dam design was utilized in order to separate the additional landscape-design features from the standard structural parts of dams that are necessary from a technical standpoint, as defined by the universally standardized dam types (Chugh, 2011; Ioannidis & Koutsoyiannis, 2017b; Tanchev, 2014).

As a result of this investigation, more than 70 cases of architectural and landscape interventions in dams were found, originating from counties across all inhabited continents. The typologies of landscape design in dams were then formed, by grouping cases of implementation of landscape design techniques with similar characteristics.

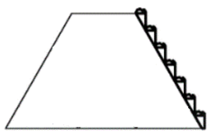
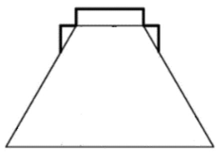
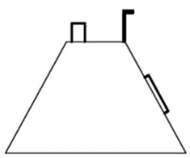
2.3.2 Landscape design: dam body

The analysis of landscape-design practice in dams demonstrated that, even though landscape design is not implemented in the majority of dams globally, a great variety of distinctive implementations can also be found. Beginning with the dams' body, architectural interventions are mainly carried out in the downstream face, which is the largest visible part of the dam. In dams built from concrete or hardfill, various different types of coatings have been used in this area. In the compiled examples (Table 1), the technique that has been most regularly utilized is ashlar masonry with natural stones both in carved and semi-carved form, using marble, slate, limestone, basalt and granite. Alternative facing techniques also include brickwork and concrete molds. In the case of the downstream face of dams that are built of earth or rock material (also called embankment dams), different techniques have been developed that mainly focus on the formation of the outer layer of the dam's material with rubble masonry. Downstream slopes have also been planted, primarily in embankment dams but also in some cases of concrete dams. In dams made from earth or rock material, the most common techniques include planting with grasses, shrubs or even trees, such as in the Aswan High dam in Egypt. In concrete dams, planting is commonly limited to planter boxes in the crest or sparsely scattered in the downstream face. However, in the La Breña II dam, completed in 2009 in Spain, it was demonstrated that full planting of the downstream slope is possible in gravity dams as well.

Table 1 Typology of techniques used in the landscape design of the dam's body and examples of cases where they have been implemented.

Dam section sketch	Type of design	Examples of dams
	Downstream slope facing	Howden (UK-England), Vyrnwy (UK-Wales), Marathon (Greece), Bornos (Spain), Cataract (Australia), Solbergofoss (Norway), Wachuset (USA), Minamiaiki (Japan), Kuriyama (Japan), Tirajana (Spain), Kurodani

[4] https://www.icold-cigb.org/article/GB/world_register/general_synthesis/number-of-dams-by-country-members

		(Japan), Pinios (Greece)
	Planted downstream face or crest	Ladybower (UK-England), La Breña II (Spain), Bhandardara or Wilson (India), Arriaran (Spain), Charco Redondo (Spain), Sorpe (Germany), Jarrama (Spain), Aswan High (Egypt), Kalangur (China), Nangoumen (China)
	Dam crest features	Kawachi (Japan), Vyrnwy (UK-Wales), Cataract (Australia), Möhnetalsperre (Germany), Jandula (Spain), Grand Dixence (Switzerland)
	Information boards, decorative elements, lighting and art	Oddatjorns (Norway), Miharu (Japan), Arriaran (Spain), Sannokai (Japan), Hume (Australia),
	Arched-buttress dams' bodies form distinctiveness	Emosson or Barberine (Switzerland), Meishan (China), Roselend (France), Navatn (Norway), Plastiras (Greece)

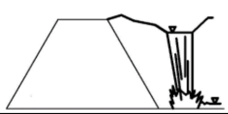
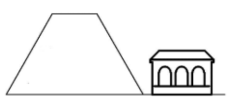
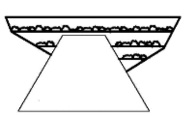
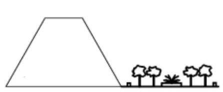
The dam crest has also been the recipient of landscape and architectural interventions. Such interventions include the design of parapets, railings and other auxiliary structures on the crest of the dam. Examples of this type of structures are valve towers (Gandy, 2006), which can be included into the architectural design of dams as demonstrated in the cases of Cataract dam in Australia or Solbergfoss dam in Norway, or viewing towers, such as in the example of Möhnetalsperre dam in Germany. Other than major architectural interventions, smaller scale designs and artistic elements can also be found in several dams of all the various dam-types; e.g., in their parapets and railings, such us the minimalistic concrete parapet of the Grand Dixence dam in Switzerland or the stone parapet of the Oddatjorndammen in Norway. Artistic interventions include sculptures, wall-painting of parts of the dam (Pérez et al., 2013; Ramos & Alonso, 2003) and inscriptions in the downstream façade of dam, such as in Sannokai dam in Japan.

Finally, the investigation also demonstrated that certain types of dams are in some cases considered to be architecturally significant even solely due to their form or their historical significance, without requiring additional landscape-design interventions. Plasticity of forms, body form distinctiveness and the structural "honesty" (Bacon, 2015) of reinforced concrete, have been identified as elements of inherent architectural and aesthetic value in dams, by Le Corbusier and others (Kreuzer, 2011; Le Corbusier, 1925); the types of dams that usually combine these structural characteristics are arch dams and buttress dams. Masonry dams are also perceived positively, but mainly due to their historical significance (García Martín, 2012) as they were a popular dam throughout European history, beginning from Ancient Greece (Dounias, 2020; Mamassis & Koutsoyiannis, 2010) and Ancient Rome (Arenillas & Castillo, 2003). Arguably, most of these dams were not affected by the "split between architecture and engineering" (Berrocal Menárguez & Holgado, 2014) that took place in the post-industrial era and contributed to the emergence of issues of landscape industrialization.

2.3.3 Landscape design: appurtenant structures and peripheral landscape

The appurtenant structures and the peripheral landscape of dams have also been incorporated into landscape designs in several cases (Table 2). In general, spillways and outlet works of dams commonly follow standardized designs that are predetermined by technical requirements. However, in the examined cases, creative non-standard-practice designs have been used to improve landscape integration (Table 2). Examples include conveying water to lateral rocky abutments, either directly below (e.g. Bhandardara-Wilson dam) or downstream of the dam (e.g. La Pena Dam in Spain) (García Martín, 2012), so that the water is finally released to flow naturally over stones, similarly to natural waterfalls. Another alternative to mainstream standardized spillway-design, is the use of customized overflow channels to convey the excess flood water directly over the downstream face of dams; a technique primary utilized in dams built from masonry (Winter et al., 2010), concrete or hardfill.

Table 2 Typology of techniques used in the landscape design of dams' appurtenant structures and peripheral landscape and examples of cases where they have been implemented.

Dam section sketch	Type of design	Examples of dams
Appurtenant structures		
	Non-standard landscape design of spillway and outlet works	Bhandardara/ Wilson (India), Jandula (Spain), La Pena (Spain), Tunhovd (Norway)
	Special cases of architectural design of spillways with overflow on dam body	Derwent (UK-England), Batanejo (Spain), Kuromata (Japan), Ovre Eggevatn (Norway), Malpaso del Calvillo (Mexico)
	Architectural design of facilities and appurtenant structures	Marathon (Greece), Bermejales (Spain), Rocky Reach (USA), Dalsfos (Norway), Pitlochry (UK-Scotland), Beni Haroun (Algeria)
Peripheral landscape		
	Restoration of excavated slopes	Fukashiro (Japan), Kitakawachi (Japan), Shimokubo (Japan), Haizuka (Japan)
	Public park in the dam area or the broader reservoir area	Asari (Japan), Haizuka (Japan), Kensico (USA), Lenexa (USA), Mettur (India), Sardar Saroar (India)

In addition to spillways and outlet works, other appurtenant structures of dams, such as water-intake towers, fish passes and power stations (in hydroelectric dams) have also been modified in efforts to improve the landscape integration of dams. Representative examples of architectural design of water-intake towers are the Marathon dam in Greece (Ioannidis & Koutsoyiannis, 2020) and the Vyrnwy Dam in Wales. Fish passes or fish ladders, as they are also called, have also been referenced in regard to their potential for successful integration into landscapes when particular landscape design techniques are followed (DVWK, 2002). Finally, power generation facilities (needed in the case of hydroelectric dams) have also been treated architecturally and various architectural design approaches have been used for their design, with references to cultural, natural and aesthetic attributes of the project's location (Table 2).

Other than the design of dam infrastructure and facilities, landscape design of dams also concerns the peripheral area of the dam. Indicative works include the rehabilitation of local landscape impacts from excavation works, landscaping the area surrounding the structural parts of the dam and construction of park infrastructure. Techniques for slope and excavation rehabilitation primarily include the use of gabions and planting. In addition to landscape rehabilitation, in various examples public parks have been constructed in the proximity of dams (Table 2). In such cases, the dam is commonly used as a central landmark of the park and the park itself is constructed close to it, usually right downstream of the dam or in its lateral abutments. Public parks in dams usually include benches, information signs for the dam, terraces, etc. In a larger scale, the construction of the dam might also include the creation of coastal trekking trails or biking paths in the periphery or the reservoir. Cases where trees were planted were also found, usually in the proximity of the dam and the reservoir area (Koutsoyiannis & Ioannidis, 2017) but also in more distant areas, as remedial measures; such us for example in Andevalo dam in Spain (Pérez et al., 2013).

2.4 Contribution of landscape design to improving landscape quality perception

The typology of landscape-design techniques that was formed in section 2.3 (Table 1 and Table 2) is used in this section to evaluate the effect of landscape design to public perceptions of dams' landscapes. This evaluation is carried out using two separate methods: (a) the investigation of the impact of the use of designs from the typologies of Table 1 and Table 2 on the numbers of photograph uploads near dams in geotagged photography databases and (b) the investigation of literature on dams, looking for positive references to dams in which the techniques that are presented in the typologies of Table 1 and Table 2 have been used; positive references had to be relevant to improvement of landscape qualities or landscape-value perception.

2.4.1 Landscape-quality perception analysis using geotagged photography databases

The level of public activity in geotagged photography web applications or social media platforms has already been used in investigations of place attachment, landscape qualities or landscape value perception (Komossa et al., 2020; Oteros-Rozas et al., 2018; Pettorelli et al., 2016; Zhang & Zhou, 2018). Thus, online geotagged photography data bases were examined in the effort to identify potential correlations between the implementation of landscape design in dams and increased landscape-value perception. The analysis of this section was limited to dams of Greece for two reasons: Firstly, because the personal experience of the authors in the dams of this country allowed for the qualitative oversight of the results. Secondly, because the required research procedures (count of photographs uploads, examination of photographs, etc.) were carried out manually thus limiting the potential for a global analysis due to the significant work-load required.

The initial step of the analysis was the selection of a group of dams and the identification of any architectural and landscape design features (such as those presented in the typologies of Table 1 and Table 2) on them. For this, we used the data set of the 27 large-dams of Greece with height over 50 m, as listed in the inventory of large dams of the Greek Committee on Large dams (Greek Committee on Large Dams [GCOLD] & TEE Larissa, 2012). Out of the 27 examined dams, three dams included any of the features of the typologies of Table 1 and Table 2: Marathon dam (Figure 1), Tavropos (also referred to as Plastiras) dam and Pinios dam (both in Figure 3). In the Marathon dam, a broad set of landscape-design interventions has been carried out in order to integrate the dam with its natural and cultural environment; the design includes downstream slope and crest facing with marble, careful architectural treatment of appurtenant structures and a public park in the abutments of the dam. The Pinios dam is the only Greek dam with a freely planted downstream slope including grass, shrubs and trees, overall managing to resemble a natural hillside. In the Tavropos (Plastiras) dam, landscape design features include the methodical architectural design of the appurtenant structures of the dam, three viewing balconies in the middle and the edges of the dam, an open market and furthermore the dam also presents architectural value in itself due to the distinctiveness of its form, being the only arch dam in Greece

The second step of the analysis was the examination of the density of uploaded images in geotagged photography data bases in the proximity of all examined dams, followed by the comparison of the number of uploads between dams with and without architectural and landscape design interventions. All uploaded photographs in Panoramio and Google Earth platforms within a buffer zone of approximately 50 m surrounding all of the dams were examined. Out of those photographs, we counted those that met either of the following two criteria: (a) captured the dam or its appurtenant structures or (b) captured the reservoir of the dam; The reservoir was also included in the analysis since the reservoir is also a derivative of the dam and its landscape significance has been highlighted in literature (Ioannidis & Koutsoyiannis, 2020), as is the presence of water in landscapes in general (Yamashita, 2002). The resultant photograph counts for the 27 examined dams are presented in Figure 2.

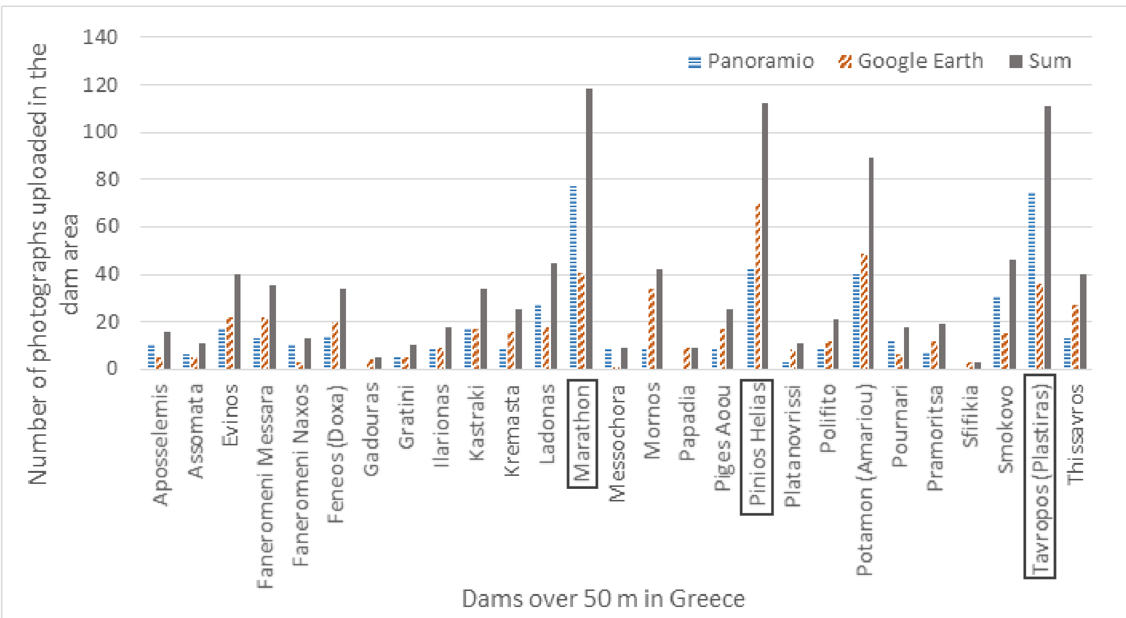


Figure 2 Count of photograph uploads in Panoramio and Google Earth geotagged-photography databases in the proximity of Greek dams with height over 50 m. The names of dams that include landscape-design features are presented inside rectangles with black outline. Data from Panoramio were collected in March of 2016 and data from Google Earth in November of 2019.

The results demonstrate that the three Greek dams with the largest number of uploaded photographs are the Marathon, Tavropos (Plastiras) and Pinios dams, followed closely by Potamon (Amariou) dam. Interestingly, the top three dams in terms of photograph-upload count are actually those that include features of landscape and architectural design, such as those listed in Table 1 and Table 2. The fourth dam in the photograph count, the Potamon (Amariou) dam, does not include any notable features of landscape design (other than a plateau for parking and viewing the reservoir in the left abutment of the dam) but also presents a high number of photograph uploads in its vicinity. It should thus be noted that high numbers of photograph uploads cannot be solely attributed to landscape design. Other parameters such us ease of access to the dam, proximity to highly populated cities, tourist load of the broader dam's area, etc. could also contribute to the larger number of photograph uploads. With that said, the strong correlation between the presence of architectural design features and the high density of photograph uploads indicates that landscape-design features probably contribute to the higher number of uploads, to some extent. Indicatively, the average photograph count in dams including architectural design features is 113.7 photographs/dam in comparison to 25.8 photographs/dam for the remaining dams.

Figure 3 Photographs of Pinios (left) and Plastiras/Tavropos dam (right)[5].

2.4.2 Analysis of literature on landscape qualities

Dams and their reservoirs have in various instances been cited in positive regard in terms of their capacity to improve landscape quality perception. This has been observed both in academic (Ananiadou-Tzimopoulou & Nana, 2015; Berrocal Menárguez & Holgado, 2014; Callis, 2015; Frolova, 2010; Frolova, Jiménez-Olivencia, et al., 2015; Ioannidis & Koutsoyiannis, 2017b; Kreuzer, 2011) and in institutional literature (Douet, 2018; Fleetwood, 2010; Norges vassdrags- og energidirektorat., 2013; Pérez et al., 2013). Attributes of dams that are cited in this regard are usually cultural, natural or purely aesthetic.

In the academic literature, the architectural and landscape design of dams have been associated with the creation of scenic landscapes (Frolova, Jiménez-Olivencia, et al., 2015), enhancing built heritage (Callis, 2015) and creating tourist attractions (Ananiadou-Tzimopoulou & Nana, 2015). Even though dams of standardized technical design, i.e. without additional landscape-design features, have also been referenced for their positive landscape contribution, either due to their form (e.g. arch or buttress dams as described in section 2.3.2) or due to the aesthetics of the natural scenery surrounding them (Sargentis et

[5] Sources: https://lh5.googleusercontent.com/p/AF1QipNTM286rj_ceC2VKN0NpGU96Bmv3mOJSKSpolu=h1440 and https://lh5.googleusercontent.com/p/AF1QipPyOqUAmI4H_EAEgRPsdeZd6Wjc9jyRhOk3jPy3=w1440-h1440-pd

al., 2005, 2021), positive contribution to landscapes is more commonly highlighted in cases where architectural and landscape design features are present (Ioannidis & Koutsoyiannis, 2017b). In Table 3, we compiled a list of dams that have been referenced positively regarding landscape qualities, built heritage or tourism and presented them alongside the corresponding landscape design features from Table 1 and Table 2 that were found in each case.

Likewise, in institutional publications, references to positive landscape-changes induced by dams are commonly associated with the presence of features of architectural and landscape design. Institutions that have published relevant reports and studies include governmental agencies for the preservation and management of natural and cultural resources such as, e.g., in Norway (Nynäs, 2013), Scotland (Fleetwood, 2010) and Spain (Pérez et al., 2013), as well as international societies for the preservation of cultural heritage (Douet, 2018). The former institutions have examined dams at a national level while the latter have approached the topic from a global perspective. Dams are referenced mostly in relation to their contribution to built-heritage but also for promoting tourism and recreation in their respective areas. Dams that include architectural interventions have in many cases been designated as monuments of cultural heritage (Douet, 2018; Fleetwood, 2010; Norges vassdrags- og energidirektorat., 2013) or as places of Interest for the Community (e.g. the Bolarque dam in García Martín (2012)) and have been included in registers of Historic Places (e.g. the Wachusett dam in the USA, listed in National Park Service - Intermountain Region Museum Services Program (2016)).

Finally, the importance of the architectural and landscape features of dams and reservoirs has also been highlighted in the context of the discussion on the emerging renewable energy landscapes (Frolova, Prados, et al., 2015). In a systematic review of literature on the topic of landscape impacts of renewable energy, hydroelectric dams were highlighted for generating, on average, the least landscape impact in comparison with the other two major renewable energy technologies that are utilized globally, i.e. wind turbines and solar panels (Ioannidis et al., 2022; Ioannidis & Koutsoyiannis, 2020). Among others, one of the origins of this differentiation is that dams do not have predefined shapes like wind turbines and solar panels but can be modified and be integrated into local landscapes through architectural and landscape design (Koutsoyiannis & Ioannidis, 2017), thus generating more positively-perceived landscape change (Keilty et al., 2016; Matveev, 1988; Sargentis, Dimitriadis, et al., 2019; Sherren et al., 2016; Thaulow et al., 2009). We have to note though that all literature referenced in this section is associated with landscape perception by individuals experiencing the finished projects and does not concern environmental impacts of dams on ecosystems or the displacement of communities; areas in which there have been important criticisms against dams.

Table 3 Dams with architectural and landscape design features and their corresponding positive references in literature, for contribution to landscape qualities, built heritage and tourism.

Type of design	References for positive contribution to landscape qualities, built heritage or tourism
Dam body	
Downstream slope facing	Jandula dam - Spain (Pérez et al., 2013), Vyrnwy dam - UK (Wales) (Douet, 2018; Roberts, 2006), Miharu dam – Japan (Japan Dam Foundation, 2011), Minamiaiki dam – Japan (Ioannidis & Koutsoyiannis, 2017b), Naramata, Minamiaiki and Sagae Dams – Japan (Japan Dam Foundation, 2021)
Planted downstream face	Charco Redondo dam – Spain (Ioannidis & Koutsoyiannis, 2017a), La Breña II dam, Spain (Pérez et al., 2013), Sorpe dam – Germany (Sorpesee LLC, 2021)

Dam crest features	Ringedalsvatn – Norway (Nynäs, 2013), Möhnetalsperre dam – Germany (Economics and Tourism LLC Möhnesee, 2021)
Information boards, decorative elements, lighting and art	Wachusett dam – USA (National Park Service - Intermountain Region Museum Services Program, 2016), Hoover dam – USA (Wilson, 1985)
Dam body form distinctiveness	(Sargentis et al., 2005) (Tavropos (Plastiras) - Greece, (Norges vassdrags- og energidirektorat., 2013) (Navatn - Norway), (Bacon, 2015) (Barberine dam - Switzerland)
Appurtenant structures	
Non-standard landscape design of spillway and outlet works	Bhandardara (Wilson) dam – India (Ioannidis & Koutsoyiannis, 2017b; Laskowski, 2017)
Architectural design of spillways with overflow on dam body	New Croton dam - USA (Laskowski, 2017)
Architectural design of facilities and appurtenant structures	Norris – USA (Bacon, 2015), Dalsfos, Vamma, Solbergfoss dams – Norway (Norges vassdrags- og energidirektorat., 2013), Pitlochry, Bonnington dams –UK (Scotland)) (Fleetwood, 2010)
Peripheral landscape	
Restoration of excavated slopes	Fukashiro dam – Japan (Ioannidis & Koutsoyiannis, 2017b), Osatogawa Dam – Japan (Japan Dam Foundation, 2003)
Public park in dam area	Miramar Reservoir and Poway lake – USA (Koutsoyiannis & Ioannidis, 2017)

2.5 Analysis of project-costs for landscape design

In this section, we investigate landscape design of dams from a project-cost standpoint, through the analysis of three case studies, aiming to gain insights on whether landscape design of infrastructure projects is necessarily associated with high additional costs or if there are cases of low-cost yet efficient landscape design.

2.5.1 Case studies: completed projects

Additional project costs for the implementation of landscape design studies in dams are expected to differ depending on type and scale of the proposed interventions. For example, the cost for the downstream face of Marathon dam in Greece, which is coated with high-quality marble, is expected to be significantly higher than the cost for the downstream face of Charco Redondo dam in Spain, which is planted with grass. Given this variability of costs for the implementation of landscape design, we investigated whether landscape design of infrastructure is necessarily associated with high additional project costs or if low-cost designs are also a possibility. In this vein, we initially found and compared the budgets of two costwise antithetical cases: La Breña II dam in Spain and Kensico dam in the USA. The two dams share common characteristics in terms of size and dam-type, as they are both gravity-type dams with heights of the same scale, 119 m for La Breña II and 94 m for Kensico dam. However, the costs for the implementation of landscape design differ significantly between the two cases.

In the case of La Breña II dam, the cost for the implementation of the selected landscape design technique on the dam was calculated at €0.67 million, i.e., 0.56% of the total project's cost, analysing the official project-cost data from ACUAES (A. Sandoval, personal communication, 2015) (more details in supplementary material). On the other hand, in the case of Kensico dam, the original dam budget could not be accessed but the budget for a rehabilitation project that largely concerned reconstruction and maintenance of the landscape design works of the dam was found and it amounted to US$31.4 million (NYC Department of Environmental Protection Public Affairs, 2005). Such a high cost for maintenance demonstrates that probably the cost for the initial construction was even higher. The significant difference in project costs between these two cases is attributed to the fact that the landscape design of Kensico dam includes highly detailed masonry, colonnades and paved terraces, all of which have significant construction and maintenance costs. On the other hand, in the La Breña II dam the project costs were kept relatively low as the primary landscape intervention carried out was the planting of the downstream slope of the dam using a low-cost innovative technique.

2.5.2 Case study: architectural re-design proposition

For a deeper insight into the costs for the implementation of landscape design in dams, we formulated a landscape-design upgrade proposition for an existing dam, so that we can analyse the cost of landscape design in dams in more detail. For the generation of the upgraded design, the typology of Table 1 was utilized as reference, taking inspiration from best-practices for potentially low-cost landscape designs. The original budget of the dam was then compared to the new increased budget, which included the additional architectural features, loosely following the research to design process of the "experiential model", as described by Milburn and Brown (2003).

In detail, the case study was carried out through the following steps: (a) The original technical plans of Filiatrinos Dam, in Greece, were collected and analysed. (b) Landscape design upgrades were designed and integrated in the original technical plans, aiming for improved landscape integration of the dam and utilizing the typology of landscape-designs of dams presented in Table 1 as a source of ideas and techniques; a basic overview of the end result of the landscape design upgrade proposition is presented in Figure 4, as designed with 3d-software (Figure 4-(B)), alongside a photo of a typical hardfill dam in Greece (Figure 4-(A)). (c) The budget for the landscape-design upgrade of the dam was calculated, following the official procedure for public-work costing in Greece, including quantity measurement and costing with the use of standard tariffs; the procedure followed was the same with the one used for the calculation of the original budget of Filiatrinos dam. (d) The original budget and the updated budget for the re-design proposition were compared.

The selection of a simplistic design with the utilization of earth material, planting and limited amounts of additional concrete and hardfill material led to relatively small increase to Filiatrinos dam budget, equal to €0.50 million, i.e., 1.41% of the total project's budget. The detailed budget of the updated architectural design is provided on the supplementary material. In Table 4 we also present the individual sub-budgets for the landscape-design upgrade of each dam part along with a summary of the budgeted tasks in each case.

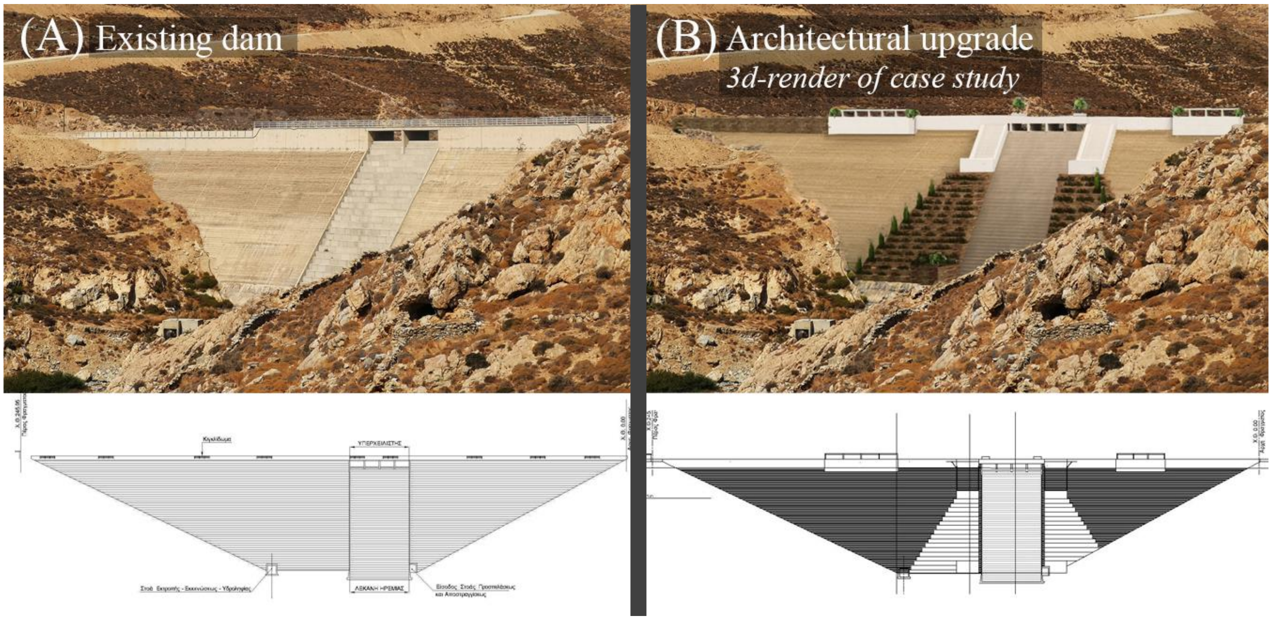


Figure 4 (A) left side: actual image of a constructed hardfill dam and common front view design. (B) right side (case study): 3d render of the architectural design proposition of the case study and front view with updated design

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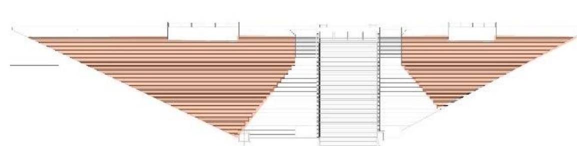
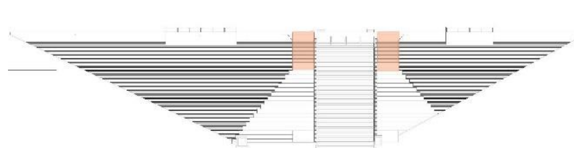
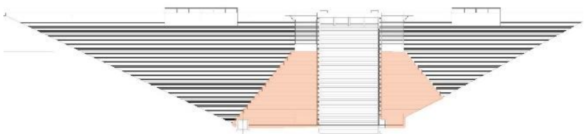
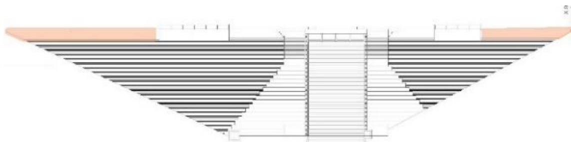
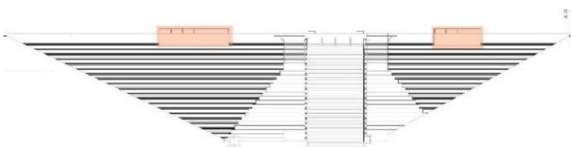
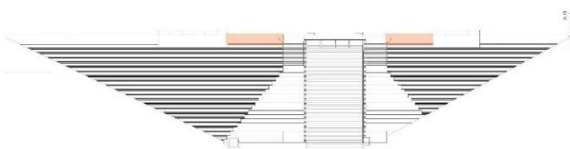
Table 4 Budget and summary of budgeted tasks for the landscape-design upgrade case study (More details on the supplementary material).

Dam zone	Budgeted tasks summary	Budget as percentage of total project budget (%)
Zone 1 - Downstream Slope hardfill moulding		
	Downstream face hardfill moulding	0.10%
Zone 2 - Downstream Slope balconies		
	Precast concrete units, concrete construction, coating and colouring	0.44%
Zone 3 - Downstream Slope planted spaces		

	Gabion assemblage and installation, preparation of green areas, planting, Irrigation system	0.48%
Zone 4 - Crest gabion facade		
	Gabion assemblage and installation	0.07%
Zone 5 - Crest balconies		
	Concrete and hardfill construction, coating and colouring	0.27%
Zone 6 - Crest concrete finish		
	Concrete coating and colouring	0.01%
Additional works (Upstream slope crest, lighting)		
	Concrete coating and colouring, lighting fixtures	0.04%
		Sum
		1.41%

3 Results - Discussion

The key findings from the analysis of landscape-design practice in dams are the following:

Technical feasibility: The compiled list of 53 dam projects in which landscape design has been applied in various different scales and styles, demonstrated that there are no insurmountable technical issues to the implementation of landscape design in dams (Table 1 and Table 2).

Perceived quality of infrastructures' landscapes: In the online geotagged photography databases of Google Earth and Panoramio, a significantly higher density of uploaded content was observed in the proximity of dams that included features of landscape and architectural design. In particular, in the largest 27 Greek dams (over 50 m in height), the average number of uploaded photographs in the proximity of the dams that included features of landscape design was 113.7 photographs per dam, in contrast to 25.8

photographs per dam in dams that did not include such features. Furthermore, in institutional and academic literature, dams that include architectural and landscape-design features have been praised for their contribution to built cultural heritage, to touristic development and to the creation of scenic landscapes. Thus, it can overall be argued that the implementation of landscape design in dam projects has contributed to improved landscape-value perceptions and landscape qualities in local landscapes.

Cost: Additional project-costs for the large-scale integration of landscape-design features in dams can be kept at the order of 1% of projects' budgets. This is supported both by the case study of La Breña II dam, constructed in Spain in 2009, and also by the calculation of additional project costs for a theoretical complete architectural re-design proposition for Filiatrinos dam, constructed in 2017 in Greece; a case study that was specifically formulated for the purposes of this study.

In regard to the limitations of our study, a significant point to be made is that the above-mentioned results originate from the analysis of landscape design practices in dams, in particular, out of all types of major civil infrastructure. It has to be noted though, that many of the results also apply to other major civil infrastructure as well. Indicatively, the typologies of landscape design in dams (Table 1 and Table 2) include various types of landscape-design techniques that are also commonly implemented in many other types of infrastructure as well, such as highways, bridges, water supply infrastructure, etc.; e.g. the restoration of excavated slopes, the architectural design of facilities and appurtenant structures, the integration of public parks in the areas of the projects, the inclusion of information boards, green infrastructure, decorative elements associated with local cultural background and architectural preferences, lighting and art installations and finally treatment of the facades of generated structural slopes. Nevertheless, more targeted research on the technical and cost-associated feasibility of landscape-design in other types of infrastructure would certainly generate valuable insights for the advancement of this field of landscape design.

It also has to be noted that in most cases presented in the landscape-design typology of Table 1 and Table 2 it is not clear whether the compiled designs are the result of targeted landscape and architectural studies or the results of individual initiatives of participating architects or engineers. Unfortunately, literature and publicly available information on the dam projects compiled did not include details on whether architects actually participated in the projects, in most cases. It can be assumed that in most large-scale implementations of architectural interventions architects have indeed participated. However, this is not certain for all cases, especially for less extensive interventions. For example, the participation of architects is confirmed in various projects in Norway, e.g. Bredo Greve in Solbergfoss dam and Thorvald Astrup in Nomeland dam (Norges vassdrags- og energidirektorat., 2013)or in the Möhnetalsperre dam in Germany, designed by Franz Brantzky[6]. However, in the La Breña II dam, for example, it is known that the planted downstream slope was designed by the dam engineers of Dragados S. A. as a measure for limiting the visual impact of the dam (A. Sandoval, personal communication, October 14, 2015).

4 Conclusions

Beginning from the global observation that landscape design is usually not implemented in major civil infrastructure projects, in this study we investigated whether this shortcoming is justified by practical or utility-related limitations or if the role of landscape-design in infrastructure projects should be reinforced. Landscape-design practice in dam projects was selected as the focus of the study, due to the fact that landscape-design interventions in dams present a wide spectrum of approaches, ranging from minor beatification efforts or full architectural studies to complete lack thereof. Thus, through the analysis of the various implementations of landscape design in dams the utility as well as the technical and economic feasibility of landscape design could be evaluated, using data from real projects and forming revealing comparisons.

[6] https://www.reisefuehrer-moehnesee.de/sehenswuerdigkeiten/moehnetalsperre/

The results demonstrated that landscape design of infrastructure projects is beneficial for landscape quality perception, cultural heritage and touristic development and that, with proper design, these benefits can even be achieved with low costs and without remarkable technical challenge. Thus, the primary policy implication of the study is that the role of landscape design in major civil infrastructure projects should be bolstered and could be supported more by policy and design guidelines or guidances. In this regard, the utilization of knowledge from global best-practice as reference and inspiration for new designs can facilitate the minimization of the technical and economic requirements for the wider integration of landscape design into infrastructure projects.

On a final note, it should be acknowledged that the results of the study are more relevant to countries with developed economies that can allocate more resources to the sustainable design of projects and that are already ahead in terms of landscape design and landscape planning policy. However, this is not to say that countries with developing economies have no capacity to integrate of landscape design in infrastructure projects, as several of the cases of dams that were presented in this study attest to the opposite.

Funding: RI was supported by the Eugenides Foundation through its Scholarships Program for Doctorate Research in the National Technical University of Athens.

Acknowledgements: We wish to recognize the help of the late Nikolaos I. Moutafis, member of GCOLD and ICOLD Technical Committee on Cemented Material Dams and the late I. Thanopoulos, member of GCOLD, as well as Dr. Ioannis Stefanakos, member of the Supervisory Board GCOLD and former sector-director in DEI/PPC (Greek Public Power Corporation). We would also like to thank Sofia Nalpantidou, Evaggelia Sadiki and Vasilios Soulis of EYDAP for helping us with photographing Marathon dam and Antonio Sandoval Zabal of ACUAES for providing us with data for La Brena II dam. We would finally like to thank Katerina Pappa for her guidance in the 3d design of the case study of architectural upgrade proposition for Filiatrinos dam.

Conflicts of Interest: The authors declare no conflict of interest

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