HERITAGE 2016

5th International Conference on Heritage and Sustainable Development

Edited by

Rogério Amoêda
Sérgio Lira
Cristina Pinheiro

Volume 2

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Proceedings of the 5th International Conference
on Heritage and Sustainable Development
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mail@greenlines-institute.org
http://www.greenlines-institute.org

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Foreword

Heritage 2016, 5th International Conference on Heritage and Sustainable Development followed the path established by previous editions of this event definitely establishing a state of the art event regarding the relationships between forms and kinds of heritage and the framework of sustainable development concepts. The number, variety and quality of papers presented and published allow a final and positive balance. As usual double-blind peer-review of papers applied and the number of definitive rejections was relatively low, confirming the over-all high quality of submitted material.

As nowadays sustainable development was brought much forward than the original concepts expressed during the last decades, *Heritage* followed that path and aimed at a broader vision on heritage and sustainable development. The role of culture and social aspects enlarged the initial statement where environment and economics took the main role, guiding the earliest research on sustainable development. The environmentalist vision of the world as a whole ecological system, and the world economical trades and product and service flows, enhanced the idea of a globalised world, where different geographic dimensions of actions, both local and global, emerged as the main relationships between producers, consumers, and cultural specificities of peoples, philosophies and religions. In such a global context, heritage becomes one of the key aspects for the enlargement of sustainable development concepts. Heritage is often seen through its cultural definition. However, sustainable development brings heritage concepts to another dimension, as it establishes profound relationships with economics, environment, and social aspects. Nowadays, heritage preservation and safeguarding is facing new and complex problems. Degradation of heritage sites is not any more just a result of materials ageing or environmental actions. Factors such as global and local pollution, climate change, poverty, religion, tourism, commerce, ideologies, war, are now in the cutting edge for the emerging of new approaches, concerns and visions about heritage.

Thus, *Heritage 2016 – 5th International Conference on Heritage and Sustainable Development* was proposed to be a global view on how heritage is being contextualised in relation with the four dimensions of sustainable development (environment, economics, society and culture) that were the core topics of the Conference. These topics brought to discussion the definition of a singular approach on how to deal with and go beyond the traditional aspects of heritage preservation and safeguarding. As presently heritage is no longer just a memory or a cultural reference, or even a place or an object, further analysis and other perspectives are in order: heritage is moving towards broader and wider scenarios, where it becomes often the driving forces for commerce, business, leisure and politics. For those reasons the topics of "governance for sustainability" and "education for the future" were also included in the programme as key factors for enlightenment of future global strategies for heritage preservation and safeguarding.

A new chapter was included in this edition of *Heritage* conferences on *Heritage and authenticity*. This chapter dealt with the specific issues of authenticity which is one of the key-words on present days discussion on heritage. Defining what is, and is not, "authentic" raises a number of serious issues, answers are not easy to reach and consensus is far from being achieved. Authenticity can be addressed as "historically true" or as depending on authorship... can be viewed as matter of "style" or as question of possession/property... can be an interpretation of material objects or a objectification of intangible concepts. In fact, authenticity is such a a complex domain that it deserves proper research and specific attention. *Heritage 2016* aimed at to contributing to the discussion on these issues, under the umbrella of sustainable development - this special chapter aimed at pushing forward a debate that is far from being a peaceful one. Papers submitted to this special chapter focused both theoretical approaches and applied research.

As in past editions of this Conference, *Heritage 2016* also gave stage to early stage researchers and students willing to share the results of their research projects, namely post-graduation projects and doctoral projects. *Heritage 2016* received a significant number of such proposals the quality of which was confirmed during double-blind review.

We would like to express our gratefulness to all the partners and sponsors of this edition of Heritage, who joined the effort to make a significant Conference. Our special recognition to the School of Arts and Humanities of the University of Lisbon and to CLEPUL, the research centre who welcomed the event.

We would also like to express our gratitude for all the cooperation and support given by the Portuguese Government - General Department of Cultural Heritage (DGPC), the Municipality of Lisbon, the Lisbon Municipal Bureau for Cultural Facilities Management (EGEAC), the Lisbon Museum and the Tourism of Lisbon.

The Organising Committee also expresses its gratitude to all Members of the Scientific Committee who reviewed the papers and made suggestions that improved the quality of individual work and the over-all quality of the event.

Last but not least, a special word of recognition to Professor Annabela Rita who welcomed us and opened all the doors so the event could become a reality.

The Editors

Rogério Amoêda
Sérgio Lira
Cristina Pinheiro

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Chapter 7

Preservation of historic buildings and structures

Large deformations in the Romanesque churches of Vall d'Aran (XII-XIII)

S. Coll-Pla, J. Lluis I Ginovart, A. Costa-Jover & A. Samper-Sosa
Unitat Predepartamental d'Arquitectura, Universitat Rovira I Virgili, Reus, Tarragona, Spain

ABSTRACT: In the *Vall d'Aran*, located on the North face of Spanish Pyrinees, there is a great number of churches. Those were built between twelfth and thirteenth century, and have suffered large geometrical deformations. This is especially true in the case of *Santa Maria de Unha* (XII) and *Santa Maria de Artíes* (XII-XIII), where the deformations are over 10% from its original shape. Puig i Cadafalch (1908) affirmed that this churches with basilica floor plant were originally built with timber frame roofs, but nowadays the oldest churches from twelfth century are covered with barrel vaults. This typology evolved to larger structures with three naves, covered by a cannon vault in the central nave, and quarter vaults in the lateral naves. These are supported by circular non-monolithic masonry columns in the centre and the perimeter walls. Several surveying campaigns in *Santa Maria de Unha* (XII) and *Santa Maria de Artíes* (XII-XIII) have been performed during last years. These combined manual direct measurements (2013-15) with topography, photogrammetry (2013-14), and Terrestrial Laser Scanner techniques (2014-15). The data obtained revealed antifunicular shapes in the barrel vaults, caused by the large displacements of the structure. This paper presents the theoretical assessment and characterisation of these deformations, which surprisingly have not caused the collapse of the structures.

1 INTRODUCTION

In the Pyrenees region of Val d'Aran, there is a set of Romanesque churches built between XIth and XIIIth centuries. The constructive typology presents the typical configuration with a central nave and two lateral naves, covered with a barrel vault and half-vaults respectively. What distinguish these buildings are the large deformations of the masonry and the buttressing strategies built through centuries to hold them.

They have called the attention of many architects and historians of construction in Spain through years. Josep Puig i Cadafalch (1867-1956) set in [1] an hypothesis about the covering of these churches. According to his theory, they should be covered with a timber structure, and transformed therefore with the construction of barrel vaults supported by non-monolithic columns and arches.

Otherwise, Joan Bassegoda i Nonell (1930-2012) [2] stated that the formal anomalies are a feature of the Romanesque architecture produced in Catalunya. Thus, specific peculiarities are set in a characteristic geographic environment; hence the importance of the early churches of Val d'Aran. One of the most relevant examples of this architecture is the church of Santa Maria d'Arties, the large movements of the masonry have deformed the structure to the limit, challenging the principles of stability. These large deformations have already been warned, described and studied by several authors as Bassegoda i Nonell [3]Villanueva [4]Saez [5]and Polo & Cots [6].

Figure 1. Inner photography of Santa Maria d'Arties.

This construction and Val d'Aran landscape are under the protection of international documents about heritage conservation like The Nara document on authenticity of 1994 [7], Carta del patrimonio vernáculo construido (1999), ratificada por la 12ª Asamblea General de ICOMOS en México [8], and the value to analysis, conservation, and restoration of structures of Architectonic Heritage of 14ª General Assembly of ICOMOS, in Victoria Falls, Zimbabwe[9].

All framed within the European Landscape convention. Florence, October 20, 2000 [10].

The Romanic structures interest carried the Escola Tècnica Superior de Arquitectura of Rovira i Virgili University to study them along (2012-13) (2013-14) courses. Three campaigns have been made now: the first, in winter (2012), studied Santa María de Arties where Basegoda (1972) noticed the big deformations; in the second campaign, in the spring (2013), Santa Maria d'Arties was studied in bigger detail; finally, in the third campaign, the studied churches were the ones from Vilamos, Salardú, Bossost and Unha. The function of the first two campaigns was to know the state of Romanic buildings around Vall D'Aran. Also, a lay out of the floorplan and sections from the named churches was obtained after the three campaigns.

The main general characteristics of the buildings are: that the churches have a basilical plan with three naves; two laterals with similar height and one higher central nave; everyone but Vilamos have a Romanic apse and all of them have a bell tower; and finally the most important characteristic is that all the churches have a central barrel vault and half barrel vault at the lateral naves.

2 BARREL VAULT DEFORMATION TIPOLOGY

The traditional elastic theory is based on resistance, stiffness and stability [11]. Thus, historical buildings as the churches of Val d'Aran are ruled by these criteria. Those structures shall be assessed considering the overall stability, which sometimes is due to its capacity to assume geometrical deformations.

The theoretical framework for the assessment of masonry structures is currently well developed, according to the principles of limit analysis defined by Heyman [12] and developed by many authors as Huerta [13]or Block et al. [14]. Those structures are subjected to compression, being far from its mechanical limits, even in the largest buildings. So, they are considered with infinite resistance to compression. Also, the tensile strength is considered to be null and the friction prevents sliding between pieces. A masonry structure, made of a rigid-unilateral material, cannot deform without cracking. Normally the deformations of a structure

are so small that we suppose that the equilibrium equations before and the after deformation are the same. [15]

There is not information about the system to build the vaults of Vall d'Aran, however, the building tradition is from Roman period.In the studies of Basilica of Maxentius, Lancaster explain that, in the section of barrel vault, can be differentiate three parts, considering symmetry. From the springing of the vault, the lower 30º angles seem to be constructed with a small curvature, the radius beings larger than that of the ideal semicircular profile. Moving up, the next part has a substantially larger curvature is close to the ideal curvature. It has been argued that they are in response to deformations of the timber centering during constructions [16].

Another possibility to explain the deformation of the barrel vault is the earthquake, it has been studied that what happened could be the cracking of vaults from a shaken with sinusoidal pulse of increasing amplitude and frequency. Lawson (2012) performed shaking tests on a fifteen-element voussoir arch hinges at 0º-36º-96º-180º. These comparisons suggest that the existence of significant tensilestrength has a substantial influence on the hinge locations. A simple alternative analysis taking account of tensile strength suggested hinge locations at 0º-56º-146º-180º. The results show us that: 2.5 HZ, 55mm amplitude sinusoidal shaking (acceleration of 13.6 m/s2): 0º-60º-133º-180º; 0.77 HZ, 56mm amplitude sinusoidal shaking (large acceleration step at the start of the loading): 0º-58º-122º-180º; 1.4Hz, 65 mm amplitude base shaking (acceleration of 5 m/s2): 0º-95º-146º-180º. [17].

The theory of equilibrium and the joint of rupture theory were completely different with the line of trust thruth. Young, in the article "Bridge" for the Supplement to the *Encyclopaedia Britannica* published in 1817 (1824), who first exposed a complete theory of arches based in the line of thrust concept. Young showed in this article a deep understanding of the concept of the line of thrust. He was the first to free the curve of equilibrium from the middle line. He stated that for arches of stone, materials with good compressive strength but low tensile strength the curve of equilibrium must lay within the substance of the arch, with some geometrical safety the curve should no approach the borders too much. The work of Moseley (1835) and Méry (1840) exerted an enormous influence. Both related the lines of thrust with the formation of collapse mechanism. Mery compared with care the results of the collapse experiments made by Boistard. He put the collapse in 28 degrees and 59 degrees from the horizontal. [18].

The formation of cracks means that the structure is not as highly indeterminate, and it becomes easier to determine where the forces are acting within the structure. In the case of a simple arch, the cracks signify hinge locations which define the position of the thrust line. The arch in its minimum thrust state provides information on the hinge locations. He put the collapse in 36 degrees and 90 degrees from the horitzontal.

3 OBJECTIVE

The data obtained revealed antifunicular shapes in the barrel vaults, caused by the large displacements of the structure. The paper presents the theoretical assessment and characterisation of these deformations, which surprisingly have not caused the collapse of the structures. It is of interest to investigate what kind of movements has produced the actual pattern of cracks.

The most likely point to find antifunicular forms is the highest part of the vault, that's the reason why we focus there our study about vault deformation. We want to remark that this study only takes into account the vault deformation, not what happens to wall and buttress.

4 METHOD

The first step taken in this investigation was to choose the churches where to focus the study. In this process, churches like Santa María de Cap d'Aran in Tredós were discarded because they contain no barrel vaults, and some were not chosen because had its vaults covered, like San Joan d'Arres de Jos.

In the end, thirteen churches are part of the study: six basilical churches (Bossost, Salardú, Vilac, Unha, Santa María d'Arties, and Vilamós); and seven churches that consist of one nave only (Bagergue, Aubert, Betrén, Arrós e Vila, San Miqueu de Vilamós, Betlan, Begós).

Next step consists in the research of antifunicular forms by the realization of topographic plans of the vaults.

The transversal section has a bigger deformation. It is due to the fact that the nave is a feebler element; the edge walls receipt the weight of vaults. The transversal section is composed by a central vault, soported by two columns, and two edge vaults soported by a wall and a column.

At Roman tradition, the columns are distributed through visual patterns. The units are distributed trhough cross-axial pair. Schemes which employ cross-axial pairs were used in Rome from the fourth to the seventh centuries, 9 and again during the twelfth and thirteenth centuries. In these two periods, however, there is a significant difference in the way the pairs of columns were arranged. In Early Christian times the elements were commonly disposed in hierarchical patterns which placed the finest or rarest shafts and capitals closest to the apse, while those of lesser value were relegated to the facade end of the colonnades. In high medieval churches, the rare or unusual elements were not necessarily placed near the apse [20]. For this reason, the section between two columns choosen to study the perpendicular deformation is indifferent. For this study, we have chosen the sections with more horizontal slopes, so the lecture is made in the perpendicular axis of churches.

After we have obtained the volumetric net of the vaults with the 3d Resheper, we make horizontal sections every ten cm in order to obtain a perfect 2D plan of the vaults.
The antifunicular deformations generate these topographic drawings:

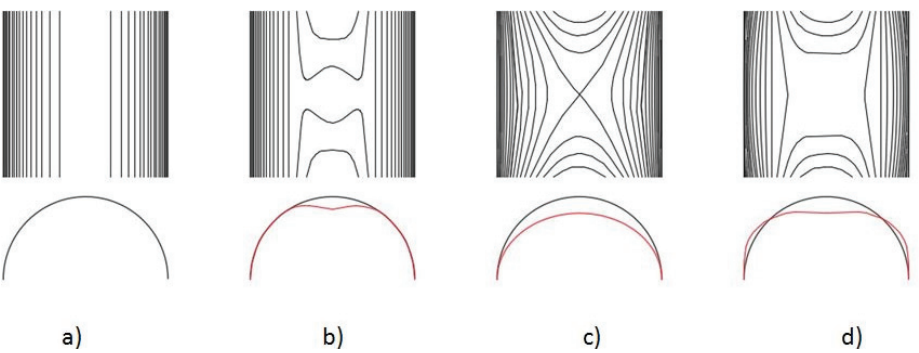


Figure 2. Deformation possible.

The image a) corresponds to a vault without deformation, the lines are parallel to each other and the distance between them gradually increases from the borders to the center.
Picture b) shows a deformation focused only in the central point, without deformation after 45 degrees. For example, we can find it in some wood covers that are supported by the central point of vault.
The detail c) is characteristic of ribbed vaults in which the central line is lower. The vault deformation is related to its composition, and the amount of stone and mortar is important. The evolution of stone shape has an inflexion point in the decades of 1020-1030 years, when the builders researched the plasticity of walls [21]. After that period, the stone was longer and with a better stereotomy. Also, there is less mortar between stones, it goes from 7-8cm to 3-4cm.
The last image (d) is a typical deformation of barrel vault where the central point is lower and the edge points are separated, as announced by Heyman. The vault may deform due to a leaning of one of buttresses. The structure deforms as a three-hinged arch and failure occurs when a fourth hinge is created on the bottom right of the base of the buttress. The expected measure is to reach a maximum lean of 3.0º before collapse, although if buttress fracturing is taken in account the lean is 2.5 [19].

5 RESULTS

The results obtained after the research and interpretation of the topographic plans are:

Bossost church has a four differentiated voids nave. All four follow a scheme type c).

The church of Salardú has a nave with four ribbed vaults, so it has been discarded from the study.

Vilac's church has a Romanesque nave with baroque presbytery. The central nave has four voids: the closest to presbytery has an a) scheme; the central vaults show a c) scheme; and the latest vault, closest to the chorus, has a d) vault scheme.

The church of Unha has a conoid volume with four vaults. The two vaults closer to presbytery have a deformation scheme type d); the central vault has a scheme type b); and the last vault has a "c" scheme deformation.

The nave of Santa Maria d'Arties has four voids from which three can be studied. They have a "d" scheme deformation.

The Church of Santa María de Vilamós has four voids. The two voids closer to presbytery show a "d" scheme and the two closer to chorus a "c" scheme.

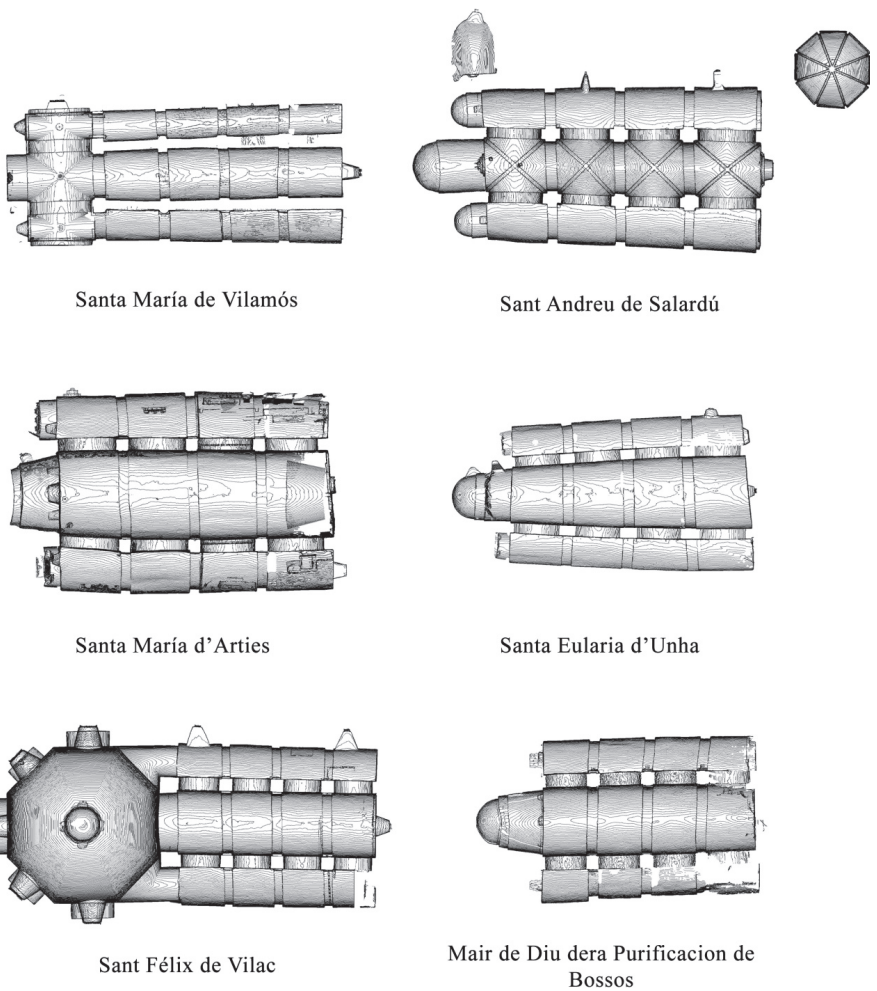
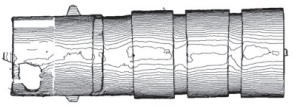
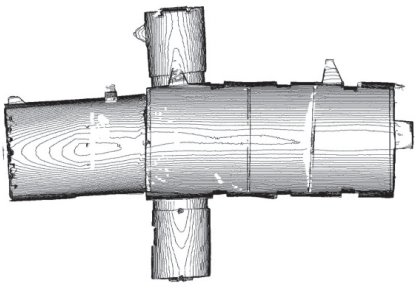


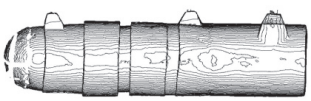
Figure 3. Tophografic plan of basilical churches.



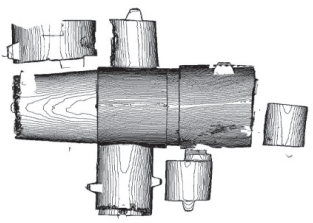
Era Mare de Diu deth Roser d'Aubert



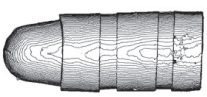
Sant Feliu de Bagergue



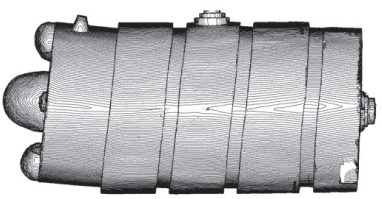
Sant Joan d'Arros e Vila



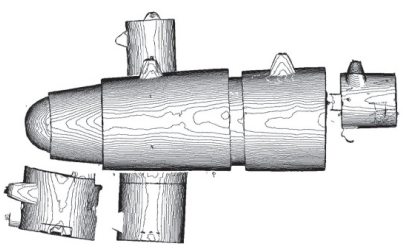
Sant Roc de Begòs



Sant Miquèu de Vilamòs



Sant Esteue de Betrèn



Sant Peir de Betlàn

Figure 4. Topographic plan of churches of a single nave.

The church of Bagergue has three pairs of columns along the nave. It has a vault without stiffening arch. The typology of deformation is closer to a "c" scheme. The deformation is strong in the third vault, closest to the chorus.

The Aubert church has a vault with two stiffening arches the deformation typology of whom is "a". Thus it has no deformation, in the other hand the vault, under the tower belt, has a deformation scheme type "c".

The church of Betrén has a vault with three stiffening arches. However, the topographic plan shows us that the vault has a unitary deformation. It has a deformation scheme "c".

The church of Sant Joan d'Arros e Vila has a nave built in different phases. The vault closer to the apse shows a "c" scheme; the next vault has an "a" scheme; the next vault has a "d" scheme; and the last vault has a "d" scheme.

The church of Sant Miquel de Vilamós has a little vault with two stiffening arches. It has a "c" scheme deformation.

The nave of church of Betlan has a stiffening arch. The two vaults have a "d" scheme deformation.

The church of Begós has a nave with stiffeness arches and they show a "d" deformation scheme.

The vertical distance between the actual vault to the hipotethic original point is in the church of Sant Félix de Vilac of 0.17m, in the church of Santa Maria d'Unha is of 0.38m, in the church of Santa Maria de Arties is of 0.28 m and in the church of Santa Maria de Vilamós is of 0.28m. The media of Basilical plan is of 0.277m. The distance in the church of simple plan is in the case of Sant Joan d'Arrós e Vila of 0.10m, in the case of church of Santa Maria de Betlán is of 0.21m and in the case of Santa María de Begós is 0.43m of distance. The media of simple plan is of 0.24m.

Table 1. Deformation of churches.

Basilical plant				Simple plan		
Vilac	Unha	Arties	Vilamos	Arros e Vila	Betlán	Begós
0.17m	0.38m	0.28m	0.28m	0.10m	0.21m	0.43m
		0.277m			0.24m	

6 CONCLUSIONS

The first visual study shows that the vaults behavior of basilical plant is different to the single plan vaults behavior. The basilical plan has lateral naves and the deformation is accommodated to void-pillar rhythm, nevertheless the church with a nave has a continuous wall.

The churches of Vilac, Unha, Arties, Santa Maria de Vilamós, Sant Joan d'Arros e Vila, Betlan and Begós, have antifunicular forms with "d" scheme deformation. The Basilical church has a bigger deformation (0.277m) to simple plan (0.24m).

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5th International Conference on Heritage and Sustainable Development

Heritage 2016 - 5th International Conference on Heritage and Sustainable Development followed the path established by previous editions of this event and definitely establishing a state of the art regarding the relationships between forms and kinds of heritage and the framework of sustainable development concepts.

Once again it was decided that the four dimensions of sustainable development (environment, economics, society and culture) should be the pillars of this event defining a singular approach on how to deal with the specific subject of heritage sustainability. Furthermore, beyond the traditional aspects of heritage preservation and safeguarding, the relevance and significance of the sustainable development concept is to be discussed and scrutinised by some of the most eminent worldwide experts.

For a long time now heritage is no longer considered as a mere memory or a cultural reference, or even a place or an object. As the previous editions of "Heritage" (2008, 2010, 2012 and 2014) have proven, heritage is moving towards broader and wider scenarios, where it becomes often the driven forces for commerce, business, leisure and politics. The Proceedings of the previous editions of this conference are the "living" proof of this trend.

Thus, ***HERITAGE 2016 – 5th International Conference on Heritage and Sustainable Development*** proposes a global view on how heritage is being contextualized in relation with the four dimensions of sustainable development. What is being done in terms of research, future directions, methodologies, working tools and other significant aspects of both theoretical and field approaches will be the aims of this International Conference. Furthermore, heritage governance, and education are brought into discussion as the key factors for enlightenment of future global strategies for heritage preservation and safeguarding.

A special chapter on Heritage and Authenticity was included in this edition, as Authenticity is one of the key-words on present days discussion on heritage. Defining what is, and is not, "authentic" raises a number of serious issues, answers are not easy to reach and consensus is far from being achieved. Authenticity can be addressed as "historically true" or as depending on authorship... can be viewed as matter of "style" or as question of possession/property... can be an interpretation of material objects or a objectification of intangible concepts. In fact, authenticity is such a complex domain that it deserves proper research and specific attention.

Heritage 2016 wants to contribute to the discussion on these issues, under the umbrella of sustainable development - this conference aims at pushing forward a debate that is far from being a peaceful one.

The Editors

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