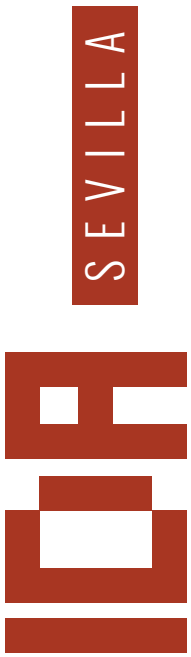
SEVILLA

IDA: ADVANCED DOCTORAL RESEARCH IN ARCHITECTURE



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FOREWORD

The Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), in collaboration with the Escuela Técnica Superior de Arquitectura (ETSAS) and the Escuela Internacional de Doctorado (EIDUS) of the University of Seville are pleased to welcome the heads of research from both Spanish and overseas universities, consolidated researchers and young doctoral researchers to the First International Congress of Doctorates in Architecture IDA Sevilla, from 27th to 28th November 2017.

The **IDA_Sevilla 2017** Congress offers a general perspective of doctoral studies in the field of Architecture and its related disciplines: urban planning, heritage, landscape, construction technologies and sustainability. In the new context generated after the elimination of the doctoral programs prior to RD 99/2011, it is necessary to carry out an analysis of the complex panorama that the former programs and the new doctoral programs have drawn up, in order to know in detail both what has been achieved so far, as well as the challenges of the future of advanced doctoral research in Spain, in the European and international context.

The startling changes that are taking place in our society call for a vision of research that is not compartmentalised into traditional disciplines or areas of knowledge. Doctoral research in Architecture must adapt to changes in society and to the sustainable productive needs of territory.

The congress will take place at the Escuela Técnica Superior de Arquitectura de Sevilla, organised in four simultaneous thematic tables, a workshop on the administration of doctoral programs and two plenary sessions.

The **thematic tables** are aimed at young doctors and doctoral students of the different participating universities who will present their experiences and methods of their research - in development or recently concluded. The participation in the thematic tables is carried out through the selection procedure with blind peer review established in the call for papers and through express invitations to the debate. The almost 70 communications have been structured in four thematic areas representative of the PhD programs in Architecture.

The **open workshop** will be held in two sessions with the participation of the coordinators of each of the collaborating programs of the Congress, and professors with extensive doctoral experience. Its objectives are multiple: to discuss the experiences undertaken in the different universities, exchange ideas about the approaches and models applied, address the challenges of internationalization and management, launch the new Industrial Doctorate with companies and public agencies, and so on.

There are two **plenary sessions**: one, a plenary session of introduction to the congress, with the participation of coordinators of national and foreign doctoral programs; and a closing plenary session, with an open debate for the going-over of the conclusions drawn from the thematic tables and the workshop, and the presentation of final conclusions.

We thank the Escuela Internacional de Doctorado of the University of Seville, and the Escuela Técnica Superior de Arquitectura de Sevilla for the support they have provided for the holding of this meeting, which contributes so much to the clarification of the future of doctoral studies in Spanish universities in the face of the great challenge of internationalization and the continuous improvement of the quality of research in Architecture. We also thank those responsible for the participating Doctoral Programs, the Architecture library of the US and all the participants and attendees.

Antonio Tejedor Cabrera
Marta Molina Huelva

Conference Chairpersons IDA_Sevilla 2017
Instituto Universitario de Arquitectura y Ciencias de la Construcción IUACC

PRÓLOGO

El Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), con la colaboración de la Escuela Técnica Superior de Arquitectura (ETSAS) y la Escuela Internacional de Doctorado (EIDUS) de la Universidad de Sevilla, se complacen en recibir a los responsables de investigación de universidades españolas y extranjeras, a los investigadores consolidados y a los jóvenes investigadores de doctorado en el I CONGRESO INTERNACIONAL DE DOCTORADOS EN ARQUITECTURA IDA_Sevilla, del 27 al 28 de noviembre de 2017.

El congreso **IDA_Sevilla 2017** ofrece una perspectiva general de los estudios de doctorado en el campo de la Arquitectura y sus disciplinas afines: urbanística, patrimonio, paisaje, tecnologías de la construcción y sostenibilidad. En el nuevo contexto generado tras la extinción de los programas doctorales anteriores al RD 99/2011 es necesario realizar un análisis del complejo panorama que han construido los programas extintos y los nuevos programas de doctorado, con el objeto de conocer con detalle tanto lo conseguido hasta ahora como los retos que depara el futuro de la investigación doctoral avanzada en España, en el contexto europeo e internacional.

Los vertiginosos cambios que se están produciendo en nuestra sociedad reclaman una visión de la investigación no compartimentada en disciplinas o áreas de conocimiento tradicionales. La investigación doctoral en Arquitectura debe adaptarse a los cambios de la sociedad y a las necesidades productivas sostenibles en el territorio.

El congreso se celebra en la Escuela Técnica Superior de Arquitectura de Sevilla organizado en cuatro mesas temáticas simultáneas, un taller sobre la gestión de los programas de doctorado y dos sesiones plenarias.

Las **mesas temáticas** están dirigidas a los jóvenes doctores y a estudiantes de doctorado de las diferentes universidades participantes que exponen sus experiencias y métodos sobre las investigaciones en desarrollo o recientemente concluidas. La participación en las mesas temáticas se realiza por el procedimiento de selección con revisión por pares ciegos establecido en la *call for papers* y por medio de invitaciones expresas al debate. Las casi 70 comunicaciones se han estructurado en cuatro áreas temáticas representativas de los programas de doctorado en Arquitectura.

El **taller** de puesta en común se realiza en dos sesiones con la participación de los coordinadores de cada uno de los programas colaboradores del Congreso y de profesores con amplia experiencia doctoral. Sus objetivos son múltiples: debatir sobre las experiencias desarrolladas en las distintas universidades, intercambiar ideas sobre los enfoques y los modelos aplicados, abordar los retos de internacionalización y de gestión, poner en marcha el nuevo Doctorado Industrial con empresas y agencias públicas, etc.

Las **sesiones plenarias** son dos: una sesión plenaria de introducción al congreso, con la intervención de coordinadores de programas de doctorado nacionales y extranjeros; y una sesión plenaria de clausura, con un debate abierto para la reelaboración de las conclusiones extraídas de las mesas temáticas y del workshop y la presentación de las conclusiones finales.

Agradecemos a la Escuela Internacional de Doctorado de la Universidad de Sevilla y a la Escuela Técnica Superior de Arquitectura de Sevilla el apoyo que han proporcionado para la realización de este encuentro que tanto contribuye a clarificar el futuro de los estudios doctorales en las universidades españolas ante el gran reto de la internacionalización y la continua mejora de la calidad de la investigación en Arquitectura. Damos los gracias también a los responsables de los Programas de Doctorado participantes, a la Biblioteca de Arquitectura de la US y a todos los participantes y asistentes.

Antonio Tejedor Cabrera
Marta Molina Huelva

Directores Congreso IDA_Sevilla 2017
Instituto Universitario de Arquitectura y Ciencias de la Construcción IUACC

OBJECTIVES

1. Analyze the research lines of the various programs and build a map of doctoral research in Spain with the support of coordinators, tutors / thesis supervisors, doctoral students and young doctors in the disciplines related to Architecture and their related areas.

2. To know the status of doctoral theses in progress or defended in the last three years, selected by means of a call with blind peer evaluation of the doctoral programs participating in the congress.

3. Discuss the structure and university management of doctoral programs in relation to employment challenges, collaboration with the productive sector and national research programs.

4. Exchange experiences with other international doctoral research programs on international mobility management, theses with international mention, co-supervised theses, theses with industrial mentions, etc.

5. No less important, consolidate a national and international network of Doctoral Programs related to Architecture, Urban Planning, Heritage, Landscape, Technologies and related disciplines.

IDA ADVANCED DOCTORAL RESEARCH SEVILLA 2020

LT 1 ARCHITECTURE TECHNOLOGIES

LT 2 HOUSING, CITY AND TERRITORY

LT 3 HERITAGE AND REHABILITATION

LT 4 ANALYSIS AND ADVANCED PROJECTS

FORMAT

Thematic tables
The thematic tables are places to present the methodologies and experiences of young doctors and doctoral students from different universities. They are managed by the doctorate students themselves, who generate conclusions to be debated and reworked in the final plenary session. The sessions are developed simultaneously with the presentation of the papers selected in the call, organized in four areas or thematic lines:

1. Architectural technologies
2. Housing, city and territory
3. Heritage and Rehabilitation
4. Analysis and advanced projects

Workshop
The workshop of the Congress is oriented towards the analysis of the problems and management needs of the Doctorate Programs, with the objective of arriving at conclusions that may be useful to the Universities involved. The coordinators of the Doctorate in Architecture programs and the doctoral students' representatives will participate in the workshop. The following are topics for debate: lines of research, methodologies, organizational needs of the doctoral programs, the International Doctorate and the Industrial Doctorate, and the future of doctoral research.

Plenary Sessions
The plenary sessions are held at the beginning and end of the Congress. In the first session of welcome and introduction to the Congress, researchers from the national and international scene and the coordinators of the doctorate programs are invited to participate. In the second plenary session an open debate is proposed for the going over of the proposals drawn from the workshop and the thematic tables. It also serves as a closing ceremony with the presentation of the final conclusions of the 2017 IDA_Sevilla Congress.

OBJETIVOS

1. Analizar las líneas de investigación de los diversos programas y construir el mapa de la investigación doctoral en España con el apoyo de los coordinadores, los tutores/directores de tesis, los doctorandos y los jóvenes doctores en las disciplinas relacionadas con la Arquitectura y sus áreas afines.

2. Conocer el estado de las tesis doctorales en marcha o defendidas en los últimos tres años, seleccionadas por medio de una *call* con evaluadores por pares ciegos de los programas de doctorado participantes en el congreso.

3. Debatir sobre la estructura y la gestión universitaria de los programas de doctorado en relación con los retos de empleo, colaboración con el sector productivo y los programas nacionales de investigación.

4. Intercambiar experiencias con otros programas de investigación doctoral a escala internacional sobre gestión de la movilidad internacional, tesis con mención internacional, tesis en cotutela, tesis con mención industrial, etc.

5. No menos importante, consolidar una red nacional e internacional de Programas de Doctorado relacionados con la Arquitectura, la Urbanística, el Patrimonio, el Paisaje, las Tecnologías y sus disciplinas afines.

IDA INVESTIGACIÓN DOCTORAL AVANZADA

LT 1 TECNOLOGÍAS DE LA ARQUITECTURA

LT 2 VIVIENDA, CIUDAD Y TERRITORIO

LT 3 PATRIMONIO Y REHABILITACIÓN

LT 4 ANÁLISIS Y PROYECTOS AVANZADOS

FORMATO

Mesas temáticas
Las mesas temáticas son lugares de presentación de las metodologías y las experiencias de jóvenes doctores y de estudiantes de doctorado procedentes de las diferentes universidades. Son gestionadas por los propios estudiantes de doctorado que generan unas conclusiones para ser debatidas y reelaboradas en la sesión plenaria final. Las sesiones se desarrollan de manera simultánea con la presentación de los *papers* seleccionados en la *call*, organizados en cuatro áreas o líneas temáticas:

1. Tecnologías de la Arquitectura
2. Vivienda, Ciudad y Territorio
3. Patrimonio y Rehabilitación
4. Análisis y Proyectos Avanzados

Taller
El workshop del Congreso se orienta hacia el análisis de los problemas y las necesidades de gestión de los Programas de Doctorado con el fin de extraer conclusiones que pueden ser útiles a las Universidades implicadas. En el workshop participan los coordinadores de los programas de Doctorado en Arquitectura y los representantes de los doctorandos. Son temas de debate: las líneas de investigación, las metodologías, las necesidades organizativas de los programas de doctorado, el Doctorado Internacional y el Doctorado Industrial, y el futuro de la investigación doctoral.

Sesiones Plenarias
Las sesiones plenarias se realizan al inicio y al final del Congreso. En la primera sesión de bienvenida e introducción al Congreso se invita a participar a expertos investigadores del panorama nacional e internacional y a los coordinadores de los programas de doctorado. En la segunda sesión plenaria se propone un debate abierto para la reelaboración de las propuestas extraídas del taller y de las mesas temáticas. Sirve también de clausura con la presentación de las conclusiones finales del Congreso IDA_Sevilla 2017.


IDA
SEVILLA

LT 1

TECNOLOGÍAS DE LA ARQUITECTURA

ARCHITECTURE TECHNOLOGIES / TECNOLOGÍAS DE LA ARQUITECTURA

RESEARCH ON ECO-EFFICIENT STRUCTURAL MORTARS

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Abstract: The main research goal is proving the possibility of using eco-efficient mortars as structural materials, to guarantee both safety and environment preservation in the strengthening/refurbishment/retrofitting of structures. After a comprehensive review on eco-efficient mortars, mechanical properties, rheological behaviour, setting times, durability, and environmental impact (GWP and EE) were analysed. Thus, a qualitative comparison between result obtained and OPC reference cement mortar was possible. Research is completed with an experimental characterisation of ashes, and mechanical test of mortar/concrete samples with plant biomass ashes. The research aims to demonstrate the feasibility and potential of plant biomass ashes in cement-based building materials. The performance from those mortars must be studied with static and dynamic loads as well as the resulting CO_2 emission reduction. Finally, this research will propose a protocol selection of eco-efficient mortars based on an analytical hierarchy process (AHP)-based assessment method.

Keywords: Structural mortar, Eco-efficient, Biomass ashes.

1. Introduction

The need to get some eco-efficient mortars as structural materials, which can guarantee both safety and environment preservation in the strengthening/refurbishment/retrofitting of structures is the basis of this research.

Firstly, it is necessary to know the definition of eco-efficient mortars. Eco-efficient mortars are mixtures of binders, aggregates, water and additions, in a way that provides some reduction of environmental pollution. At the same time, mechanical properties must be appropriate to use them as structural building materials.

Knowing mortar composition, it is easy to notice that the nature and amount of binder and additions are the most critical factors to improve the eco-efficient level of the mortar. Among binders, one of the most contaminant materials due to the amount of energy that needs to be generated and CO_2 emissions is the cement. Currently, cement is one of the most used building materials in contemporary architecture.

As a result, the research takes on the definition of eco-efficient mortar as those which composition has the minimum cement percentage, but guarantees both mechanical properties and construction safety. The use of additions has two benefits. First, the waste reduction is promoted, as wastes are immobilised without polluting the environment. And second, recycling those either organic or inorganic wastes makes it possible to reduce the polluting wastes that are not accumulated in landfills, improving sustainability.

Therefore, this research focuses on the feasibility of using vegetal biomass ashes as cement substitute in eco-efficient mortars by: (i) analysing their performance from a structural safety framework, (ii) analysing the environmental benefits in terms of carbon dioxide emissions, and (iii) developing a protocol selection of eco-efficient mortar based on mechanical and environmental issues.

2. Eco-efficient structural mortars

Eco-efficient mortars are those in which ordinary Portland cement (OPC) is totally or partially substituted. A first literature review focuses on cement substitutes able to reduce wastes and environment pollution. The curious reader is referred to the paper *The use of structural eco-efficient mortars. A critical review from a SWOT analysis* (González-Kunz, Pineda, Brás, & Morillas, 2017) presented in the International Congress on Sustainable Construction and Eco-efficient Solution. This article shows findings obtained from mortars with total or partial cement substituted by organic or inorganic materials.

2.1. *Eco-efficient structural mortars to be addressed*

To improve the understanding, the mortar compounds can be classified as organic or inorganic. For instance, organic substances are rice husk ash, palm oil fuel ash or sugarcane bagasse ash. Inorganic substances are for example fly ash, ground granulated blast furnace slag or limestone powder.
In general, it is possible to say that organic substitutes provide more benefits, because the waste reduction is promoted, as the wastes are immobilised, avoiding or minimizing the environment pollution. At the same time, it is important to encourage the use of vegetal ashes as they are obtained from combustion of biomass, and produce energy with the process.
A SWOT analysis is performed for the organic-cement binder mortars, due to their highest contribution to sustainability. As a main result, it is worth to highlight results in Tables 1-3:

1. Rice husk ash cement binder mortar: the properties provided to the mortar and the high production levels of this waste generate a valuable material to improve construction sustainability.

Table 1 SWOT of rice husk ash cement mortar (González-Kunz, Pineda, Brás, & Morillas, 2017)

STRENGHTS	WEAKNESSES
- High pozzolanic activity - Compressive strength enough to be used as retrofitting mortar	- Worse setting time due to its fineness, which requires more water to react
OPPORTUNITIES	**THREATS**
- One of the plant products most consumed worldwide.	- Handling and transportation of rice husk ash is problematic due to its low density

2. Palm oil fuel ash cement binder mortar: it is worth highlighting the increase of POFA production as well as the good properties provided to mortar.

Table 2 SWOT of POFA-cement mortar (González-Kunz, Pineda, Brás, & Morillas, 2017)

STRENGHTS	WEAKNESSES
- High compressive strength value with 10% substituted	- POFA decreases the flow tendency due to the increased fineness.
OPPORTUNITIES	**THREATS**
- The high quantity of production and its growing of palm oil annually.	- Inexistent mechanism to take advance of the increasing use of palm oil waste.

3. Sugar cane bagasse ash cement binder mortar: this mortar presents the best values of compressive strength.

Table 3 SWOT of SCBA-cement mortar (González-Kunz, Pineda, Brás, & Morillas, 2017)

STRENGHTS	WEAKNESSES
- The compressive strength of SCBA-cement mortar increases directly to the amount of SCBA	- In the SCBA mortar, the higher porous texture increases the water demand, and consequently decreases the flow value, thus resulting in a reduced workability
OPPORTUNITIES	**THREATS**
- Ethanol from sugarcane has been recognised as the principal biofuel for the gasoline market, consequently, it provides the SCBA growing up.	- The lack of sustainable system of management for their waste.

Additionally, it is worth mentioning some of the mechanical properties of other cement mortars with inorganic partial substitution:

1. Cement binder with fly ash substitute: this mortar can reach around 37 MPa at 28-day of compressive strength where the mixture is formed by 52% of cement substituted and a w/c radio 0.30 (Berry, Hemmings, & Cornelius, 1990).
2. Cement binder with ground granulated blast furnace slag substitute: Barnett et al. (Barnett, Soutsos, Millard, & Bungey, 2006) stated that the compressive strength with 35% of ground granulated blast furnace slag at 20 ºC at 8-day is 24 MPa.
3. Cement binder with limestone powder sustitute: mortars formed with 10% of limestone substituting cement reach 55.5 MPa compressive strength at 28-day (Benn, Baweja, & Mills, 2014).

Results from the literature review and SWOT analysis demonstrate the possibility of using eco-efficient mortars as structural materials, being safe and more environmentally friendly.

2.2. *Feasibility as eco-efficient structural mortars with plant biomass ashes in cement-based building materials*

The next step in research is to focus on the vegetal biomass ashes from energy plants. The feasibility of these mixtures as eco-efficient structural mortars is analysed. To draw a comparison between mortars, physical-chemical properties (pozzolanic activity and mechanical characteristics), rheological behaviour, setting times, drying shrinkage, durability and environmental features are analysed. In addition, the Global Warming Potential (GWP), and Embodied Energy (EE) of the plant biomass ashes- based mixtures are calculated.

Based on the literature review, the following plant biomass ashes are analysed: rice husk ash (RHA), palm oil fuel ash (POFA), sugarcane bagasse ash (SCBA), wood waste ash (WWA), bamboo leaf ash (BLA), corn cob ash (CCA), olive biomass fly ash (OBFA), agave biomass ash (ABA), cork waste ash (CWA), wheat straw ash (WSA), waste paper sludge ash (WPSA) and coconut shell ash (CSA).

The development of this research part is shown in the paper called *Plant biomass ashes in cement-based building materials. Feasibility as eco-efficient structural mortars and grouts* (González-Kunz R., Pineda, Bras, & Morillas, 2017). Advantages and disadvantages of each waste as cement substitute are highlighted. Besides, the properties or characteristics that require additional research are pointed out.

Firstly, a general description, other possible uses and details of each plant biomass ash are provided. For instance, it is interesting to highlight that rice is, among the analysed raw materials, the most abundant agricultural product. Around 740.2 million tons of rice were produced in 2015 (The Food and Agriculture Organization (FAO)'s Rice Market Monitor, 2015) and some underdeveloped countries find in rice a potential opportunity to generate energy (Hensley Duku, Gu, & Ben Hagan, 2011).

Because analysing the feasibility, as eco-efficient structural mortar, of different biomass ashes is the main concern of this research, the analysis of the physical-chemical properties is a crucial issue. According to mechanical properties, a review and analysis of pozzolanic activity, which is directly related to mechanical characteristics, and general physical-mechanical properties is provided.

It is important to highlight that to present pozzolanic activity, silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus iron oxide (Fe_2O_3) should be part of the chemical composition, in a proportion greater than or equal to 70% (American Society for Testing and Materials, 1994). Besides the ratio CaO/SiO_2 must be greater than 1 to maintain the basicity index in the material (Nkinamubanzi, Baalbaki, & Bickley, 1998). It is important to note that the $SiO_2+Al_2O_3+Fe_2O_3$ content of sugarcane bagasse ash is 89.65% (Arif, Clark, & Lake, 2016) and 81,92% in Martirena Hernández et al. study (Martirena Hernández, Middendorf, Gehrke, & Budelmann, 1998). Additionally, Wang et al. (2005) demonstrated that high amounts of reactive SiO_2 and Al_2O_3 result in higher degree of geopolymerization and consequently higher mechanical strength.

Results regarding compressive strength of eco-efficient structural mortars and reference cement mortar are crucial to this research. That is because this research searches for eco-efficient structural mortars which guarantee both safety and environment preservation in the strengthening/refurbishment/retrofitting of structures. Results of compressive strength are shown in **figure 1.** It can be seen that the best mixtures are those containing sugarcane bagasse ash (SCBA), waste sludge paper ash (WSPA), palm oil fuel ash (POFA) and corn cob ash (CCA) as they improve the reference OPC strength.

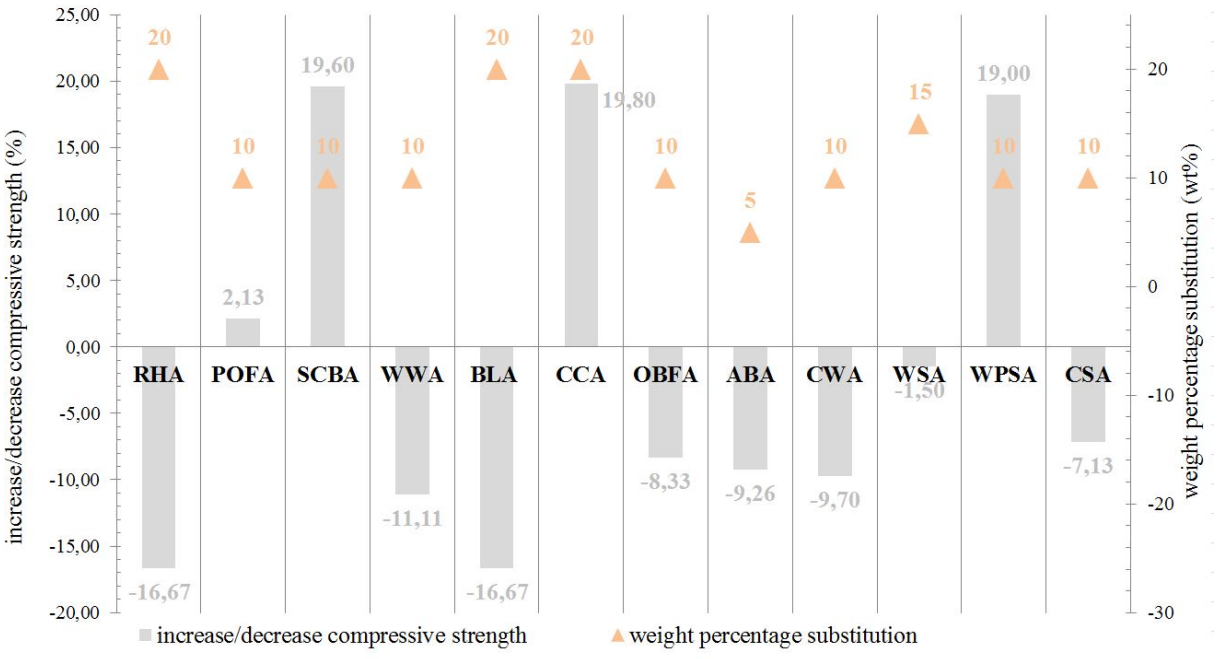

Figure 1 Compressive strength of the plant biomass ashes: increase/decrease percentage with respect to the reference ordinary Portland cement compound.

Besides mechanical properties, this research considers rheological behaviour of eco-efficient mortars. Thus, a completed vision about eco-efficient mortars is obtained. Flow spread, consistency, workability and morphological features obtained from SEM images were analysed from literature review as rheological behaviour of eco-efficient mortars. Regarding consistency and workability of OBFA-cement mortar is suitable, although palm oil fuel ash (POFA) cement mortar shows potentially satisfactory rheological behaviour.

Setting time is a crucial factor in workability, and it is split into two: initial and final setting time. The initial setting time provided by RHA, SCBA, BLA, CCA, WSA, WPSA and CSA are satisfactory as an increase with respect to the OPC reference value is observed. As far as the final setting time is concerned, although all the nominal values are acceptable, only the final setting time of the RHA decreases with respect to the reference mortar.

The drying shrinkage values of sugarcane bagasse ash (SCBA) and waste sludge paper ash (WPSA) are more satisfactory than that of the control mix whereas palm oil fuel ash (POFA) present equal values to reference cement mortar. It is worth noticing that for the rest of ashes studied no data have been found.

Durability is essential to avoid unnecessary renovations through service life. Resistance to chloride ion penetration and resistance to sulphate are key factors to the durability in cement compounds. Regarding the service life in marine environments, although sparse information is available, cork waste ash (CWA) exhibit worse behaviour with respect to ordinary Portland cement. As far as sulphate resistance is concerned, corn cob ash (CCA) and palm oil fuel ash (POFA) mortars get worse values than reference cement mortar. Finally, rice husk ash mortar is worse than OPC reference mortar in both cases.

Another important information to compare eco-efficient cement mortars is their environment impacts. Global warming potential (GWP) and embodied energy (EE) of mortars and mixes from literature review are studied and assessed. It is important to highlight that these values were assessed at the same proportions as the rest of properties aforementioned. **Figure 2** shows the Global Warming Potential (GWP) nominal values of eco-efficient structural mortars studied. All the analysed biomass-based mortars reduce the cement mortar emissions, but only partial information has been found. The Embodied Energy (EE) value is calculated in the same way that GWP, and values are shown in **figure 3.**

Figure 2 Global Warming Potential of biomass ash-cement compounds ($kgCO_2$-eq/m_2) for different cement replacement percentage (from 0 to 20%) (González-Kunz R. , Pineda, Bras, & Morillas, 2017)

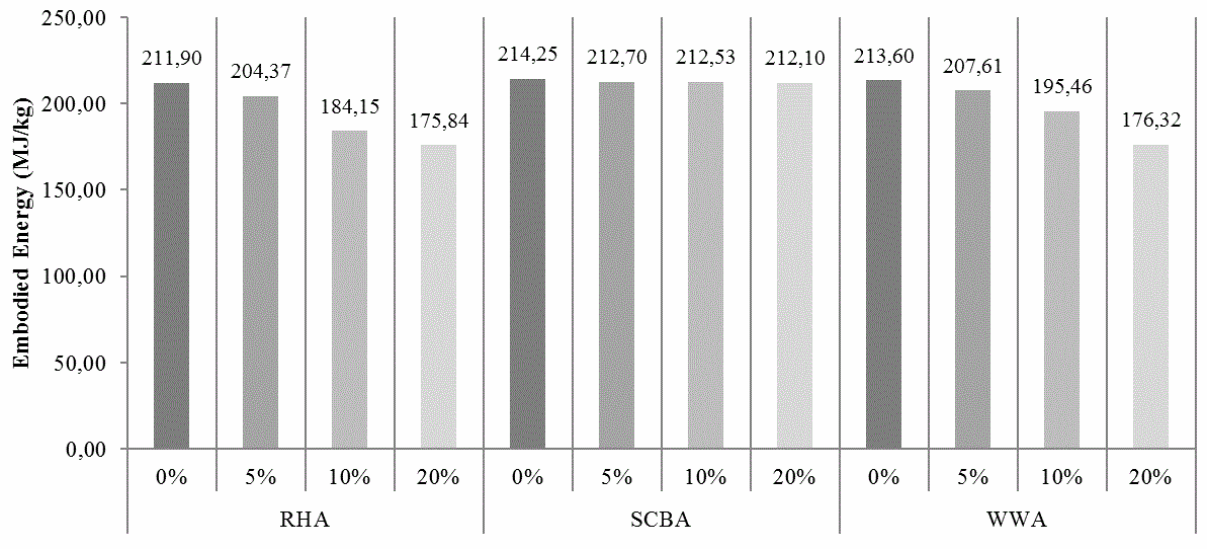

Figure 3 Embodied Energy of biomass ash-cement compounds (MJ/kg) for different cement replacement percentage (from 0 to 20%) (González-Kunz R. , Pineda, Bras, & Morillas, 2017)

Regarding the Global Warming Potential and Embodied Energy of the plant biomass ashes-based mortars, it is worth noting that all of them improve the value of reference OPC mortar. For instance, bamboo leaf ash as cement susbtitute present the least value of GWP of materials studied. The Embodied Energy values of the analysed plant waste-based mortars rice husk ash (RHA) and wood waste ash (WWA) are lower than those of the OPC reference mortar, while sugarcane bagasse ash (SCBA) improves it slightly.

To summarize, **figure 4** shows main characteristics of the analysed plant biomass ashes-based mixtures from a qualitative perspective, and in comparison to reference cement mortar properties. The lack of knowledge on some issues is left blank.

Figure 4 Main characteristics of the analysed plant biomass ashes-based mixtures from a qualitative perspective (González-Kunz R, Pineda, Bras, & Morillas, 2017)

2.3. *Chemical and mechanical studies on eco-efficient mortars with local bioashes*

Finally, we analysed the performance mortar and concrete mixes with 4 vegetal ash samples from biomass energy plants in Spain. The ashes origin are olive, wood and pruning wastes. Chemical and mechanical tests are needed to investigate properties of ashes, and how they influence mortars properties.
We carried out the following ashes characterization tests:

- Size analysis: this test shows particle size distribution.
- Pictometer: characterization of real density.
- BET method under N_2 adsorption: shows particle surface area.
- Thermal gravimetric analysis (TGA): organic content, inorganic content, degradation mechanisms and decomposition patterns from ashes will be known.
- Differential thermal analysis (DTA): exothermic/endothermic reactions, phase changes and diagrams, enthalpy change and ashes decomposition will be studied.
- X-ray diffraction: characterization of crystalline material and identification of fine-grained minerals of ashes.
- X-ray fluorescence spectroscopy (XRF): this test shows elemental and chemical composition, major chemical analysis; trace elements and semi-quantitative identification ashes.

These tests follow current Standards and codes, which are also studied to offer a comparison with the additions normally used. The analysis of test results obtained is in progress, but it is possible to say that several ashes present low pozzolanic activity due to ashes characterization.
Mechanical tests on 4x4x16cm mortar samples were carried out according to European Code EN 196-1:2004 (European Committee for Standarization, 2005). In these samples, ordinary portland cement CEM I 42.5 R is substituted by 5, 10 and 20% weight of vegetal biomass asshes. Three specimens were made of each mixture following EN 1015-11:1999. Two of three specimens obtained from each mixture are tested at 28-days, whereas the third one is tested at 90-days.
Figure 5 and **figure 6** show the results of compressive strength, flexural strength, and density in comparison to OPC mortar samples. The general trend is for a decrease in material properties as the amount of ashes increases. Mortars with ashes A02 (in grey) and A03 (in red) present low values and can be disregarded as structural materials. Taking account findings obtained, concrete mixes with the remaining two biomass ashes were prepared and casted in cylindrical 150x300mm moulds. The percentages of cement substituted were 5 and 10% by weight. Results from slump tests and 28-day

concrete strength are in progress. These tests are designed to characterise and consolidate knowledge on the performance of local biomass ashes.

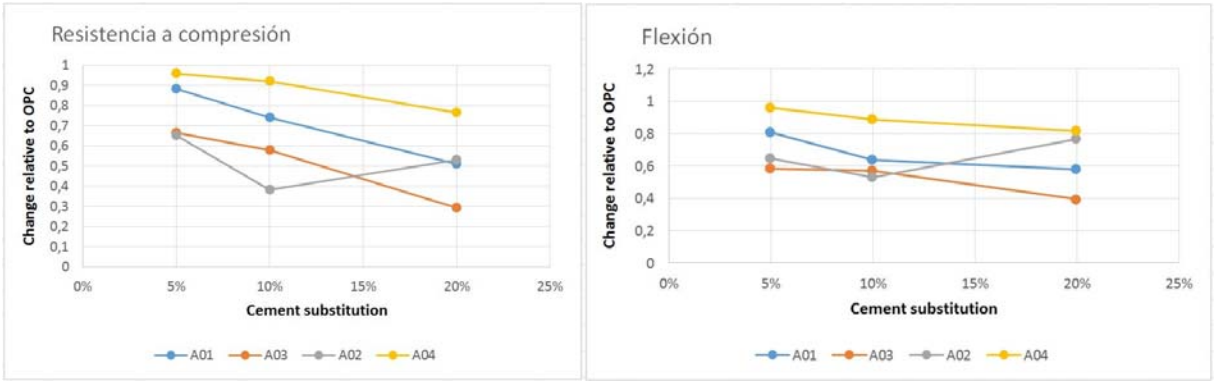

Figure 5 Preliminary results of mechanical tests of eco-efficient structural mortars. Compressive and flexural strength.

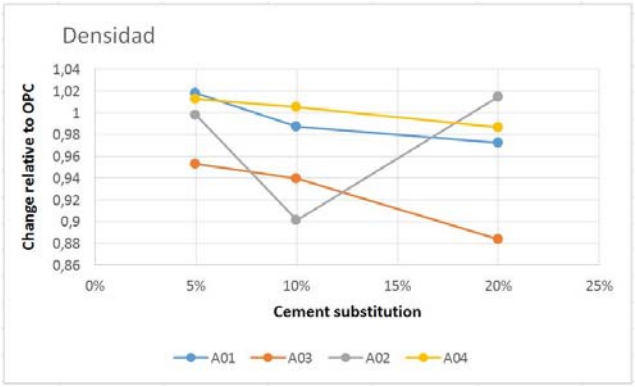

Figure 6 Preliminary results of mechanical tests of eco-efficient structural mortars. Density.

3. Conclusions

This paper shows that plant biomass ashes produce eco-efficient structural mortars, and are feasible for cement based building materials. Based on an extensive literature review, previous papers and conference communications compare results and show the progress achieved in this field. We compare from a qualitative perspective results of eco-efficient structural mortars and reference cement mortars. These are focused on mechanical properties, rheological behaviour, setting time, drying shrinkage, durability, and environment impact (GWP and EE) of eco-efficient structural mortars. The research is completed with mechanical tests of eco-efficient mortars with biomass ashes from energy plants used as cement substituted and ashes characterization.

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