

# ICIST

Instituto de Engenharia de Estruturas, Território e Construção

## Scientific and Technological Projects



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Draft

# ICIST

# SCIENTIFIC AND TECHNOLOGICAL PROJECTS (Competitive Funding)

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# Generalised Beam Theory (GBT) – Development, Application and Dissemination

PTDC/ECM/108146/2008

**KEY WORDS:** Numerical modelling; Thin-walled metal and composite (FRP) structures, Buckling and post-buckling analysis; Vibration and dynamic analysis

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**COORDINATOR(S):** Dinar Camotim (ICIST-IST)

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## SUMMARY

There were three main objectives of this project, which consisted of:

- (I) The completion of the development, numerical implementation and application of the GBT formulations in progress at the time, or the addition of new capabilities to others already available (recall that more than one year elapsed between the date in which the project proposal was submitted and the date in which the project actually began).
- (II) The development, implementation, validation and illustration of novel GBT formulations to solve structural problems not tackled before by means of this approach – this involves acquiring in-depth knowledge concerning the problems under consideration and, thus, requires a fair amount of original derivations and careful validation procedures.
- (III) The promotion and dissemination of the use of GBT amongst the scientific and technical communities.

Regarding the first objective, the work planned dealt with:

- (I.1) The local and global dynamic behaviour of steel members with open cross-sections subjected to impulsive and moving loads.
- (I.2) The local, distortional and global buckling behaviour of simple steel frames made of members with (i) plain and lipped  $\square$ -sections, (ii) plain and lipped channel sections and (iii) square or rectangular hollow sections, all subjected to arbitrary loadings. The frames may exhibit localised restraints, different joint configurations and various support conditions.
- (I.3) The local and global vibration behaviour of (i) isotropic and orthotropic (FRP composite) elastic members with different cross-section

geometries, and also (ii) simple frames built from members with open and/or tubular cross-sections.

- (I.4) The local, distortional and global post-buckling behaviour of (i) isotropic and orthotropic (FRP composite) elastic members with different cross-section geometries, and also (ii) simple frames built from members with open and/or tubular cross-sections.
- (I.5) Specific problems with practical relevance dealing with the first-order, buckling, vibration and dynamic behaviour of several structural systems, namely steel and composite steel-concrete bridges.

Concerning the second objective, research activity was carried out on the following topics:

- (II.1) New methodologies to perform the GBT cross-section analysis, aimed at acquiring fresh in-depth knowledge and improve the computational efficiency of this key GBT procedure.
- (II.2) Include additional features to enable performing buckling analyses that can capture (i) the influence of the location of the point of application of a transverse load and (ii) the web crippling phenomenon.
- (II.3) Local, distortional and global buckling behaviour of steel arches and curved members.
- (II.4) Elastic-plastic behaviour of steel members and simple frames.
- (II.5) Local and global buckling and post-buckling behaviours of trusses and frames built from tubular members.
- (II.6) Application of GBT analyses to solve (or help solving) problems associated with assessing the response and behaviour and providing design rules/guidelines for thin-walled members or structural systems with practical relevance.

Finally, regarding the promotion and dissemination of the use of GBT structural analyses, the development of user-friendly and easy-to-use computer programs and user manuals was also addressed in the project.

## **DELIVERABLES**

### **A. Book Chapters**

A.1 Camotim D, Basaglia C, Silva NF, Silvestre N, "Numerical Analysis of Thin-Walled Structures Using Generalised Beam Theory (GBT): Recent and Future Developments", Computational Technology Reviews, Volume 1, B. Topping et al. (eds), Saxe-Coburg Publications, 315-354, 2010.

### **B. Edition of International Journal Special Issues**

B.1 Guest Co-Editor, with Miroslav Skaloud, of a Special Issue of the International Journal of Structural Stability and Dynamics on "Stability and Non-Linear Behaviour of Steel Structures" - Vol. 11, nº 5, 2011.

B.2 Guest Co-Editor, with Benjamin Schafer, of a Special Issue of the Journal of Structural Engineering (ASCE) on "Cold-Formed Steel Structures" - Vol. 139, nº 5, 2013.

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C.10 Silvestre N, Camotim D, Silva NF, "Generalised Beam Theory Revisited: from the Kinematical Assumptions to the Deformation Mode Determination", International Journal of Structural Stability and Dynamics, 11(5), 969-997, 2011.

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C.13 Dinis PB, Camotim D, Silvestre N, "On the Mechanics of Thin-Walled Angle Column Instability", Thin-Walled Struct, 52(March), 80-9, 2012.

C.14 Dinis PB, Batista E, Camotim D, Santos E, "Local-Distortional-Global Interaction in Lipped Channel Columns: Experimental Results, Numerical Simulations and Design Considerations", Thin-Walled Structures, 61(December), 2-13, 2012.

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- C.22 Landesmann A, Camotim D, “On the Direct Strength Method (DSM) Design of Cold-Formed Steel Columns Against Distortional Failure”, *Thin-Walled Structures*, 67(June), 169-187, 2013.
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- C.26 Silvestre N, Camotim D, “Generalized Beam Theory to Analyze the Vibration of Open-Section Thin-Walled Composite Members”, *Journal of Engineering Mechanics (ASCE)*, 139(8), 992-1009, 2013.
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- C.32 Gonçalves R, Camotim D, “Buckling Behaviour of Thin-Walled Regular Polygonal Tubes Subjected to Bending or Torsion”, *Thin-Walled Structures*, 73(December), 185-197, 2013.
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D.8 Dinis PB, Camotim D, "Buckling, Post-Buckling and Strength of Cruciform Columns", *USB Proceedings of SSRC Annual Stability Conference (Pittsburgh, 10-14/5)*, 2011.

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#### **E. Articles in National Journals**

E.1 Camotim D, “Análise de Estabilidade Utilizando a Teoria Generalizada de Vigas (GBT)”, Revista “Metálica” (Cmm), nº 30, 6-12, Junho de 2013.

#### **F. Articles in National Conference Proceedings**

F.1 Silva NF, Camotim D, Silvestre N, Correia JR, “Comportamento Linear e Estabilidade Local e Lateral por Flexão-Torção de Vigas Pultrudidas de GFRP”, Actas em CD-ROM do Encontro Nacional de Materiais e Estruturas Compósitas (Porto, 8-10/9), AJ Ferreira (ed), 2010.

F.2 Abambres M, Camotim D, Silvestre N, “Análise Físicamente Não-Linear de Vigas Metálicas no Contexto da GBT”, Actas do VIII Congresso de Construção Metálica e Mista (Guimarães, 24-25/11), LS Silva et al (eds), 295-304, 2011.

F.3 Graça A, Basaglia C, Gonçalves R, Camotim D, “Estabilidade de Madres de Aço Enformadas a Frio Considerando a Interação com as Chapas de Cobertura”, Actas do VIII Congresso de Construção Metálica e Mista (Guimarães, 24-25/11), LS Silva et al (eds), 373-382, 2011.

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F.5 Basaglia C, Camotim D, “Dimensionamento de Vigas Contínuas de Aço Enformadas a Frio”, Actas do VIII Congresso de Construção Metálica e Mista (Guimarães, 24-25/11), LS Silva et al (eds), 345-354, 2011.

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Metálica e Mista (Guimarães, 24-25/11), LS Silva et al (eds), 335-344, 2011.

#### **G. Ph.D. Theses Concluded**

G.1 Rui Alexandre Silva Bebiano, “Stability and Dynamics of Thin-Walled Members – Application of Generalised Beam Theory”, Tese de Doutoramento em Engenharia Civil, IST, Universidade Técnica de Lisboa, 2010. (Orientador e Co-Orientador Científicos: Dinar Camotim e Nuno Silvestre)

G.2 Nuno Miguel de Freitas Silva, “Behaviour and Strength of Thin-Walled Laminated FRP Composite Structural Elements”, Tese de Doutoramento em Engenharia Civil, IST, Universidade Técnica de Lisboa, 2013. (Orientador e Co-Orientador Científicos: Dinar Camotim e Nuno Silvestre)

#### **H. Ph.D. Theses in Progress**

H.1 Miguel da Silva Abambres, “Análises Elasto-Plásticas de 1ª e 2ª Ordem de Perfis Metálicos de Parede Fina Utilizando a Teoria Generalizada de Vigas”, Tese de Doutoramento em Engenharia Civil, IST, Universidade de Lisboa, submetida em Setembro de 2013 e a defender no início de 2014. (Orientador e Co-Orientador Científicos: Nuno Silvestre e Dinar Camotim)

H.2 Pedro Alexandre Simões Martins Natário, “Web Crippling Behaviour and Design of Thin-Walled Steel Beams”, Tese de Doutoramento em Engenharia Civil, IST, Universidade de Lisboa, será submetida e defendida em 2014. (Orientador e Co-Orientador Científicos: Nuno Silvestre e Dinar Camotim)

#### **I. M.A.Sc. Dissertations Concluded**

I.1 Rui Pedro Trindade Fena, “Interacção entre Instabilidade Local e Distorcional em Colunas de Aço Enformadas a Frio com Secção em ‘Hat’”, Dissertação de Mestrado em Engenharia Civil (Estruturas), IST, Universidade Técnica de Lisboa, 2011. (Orientador e Co-Orientador Científicos: Pedro Borges Dinis e Dinar Camotim)

#### **J. Software Supporting Material**

J.1 Bebiano R, Silvestre N, Camotim D, “GBTUL 1.0.0: GBT Theoretical Background”, Technical University of Lisbon, 2010. (available at <http://www.civil.ist.utl.pt/gbt/>)

J.2 Bebiano R, Silvestre N, Camotim D, “GBTUL 1.0.0: User Manual”, Technical University of Lisbon, 2010. (available at <http://www.civil.ist.utl.pt/gbt/>)

J.3 Bebiano R, Silvestre N, Camotim D, “GBTUL 1.0.0: Illustrative Examples – Multimedia Tutorials”, Technical University of Lisbon, 2010. (available at <http://www.civil.ist.utl.pt/gbt/>)

#### **K. Software Developed**

K.1. Bebiano R, Pina P, Silvestre N, Camotim D, “GBTUL 1.0.0 – Buckling and Vibration of Thin-Walled Members”, Technical University of Lisbon, 2010. (freeware available at <http://www.civil.ist.utl.pt/gbt/>)

K.2. Bebiano R, Camotim D, Gonçalves R, Silvestre N, “GBTUL 2.0 – GBT Buckling and Vibration Analysis of Thin-Walled Members”, University of Lisbon, 2013. (freeware available at <http://www.civil.ist.utl.pt/gbt/>)

#### **L. Organisation of Events**

##### **A. Conferences**

A.1 Nuno Silvestre was a member of the Organising Committee of the Congreso de Métodos Numéricos en Ingeniería 2013, which took place in Bilbao on 25-28 March, 2013.

##### **B. Mini-Symposia and Special Sessions**

B.1 Dinar Camotim co-organised (together with Pizhong Qiao), in the context of the 2010 ASCE Engineering Mechanics Institute Conference (Los Angeles, 8-11/8/2010), a Mini-Symposium on “Stability of Solids and Structures”, which comprised four sessions.

B.2 Dinar Camotim co-organised (together with Noël Challamel, Pizhong Qiao, Yang Xiang and Jifeng Xu), in the context of the 2011 ASCE Engineering Mechanics Institute Conference (Boston, 2-4/6/2011), a Mini-Symposium on “Stability of Composite Structures”, which comprised three sessions.

B.3 Dinar Camotim and Nuno Silvestre co-organised, in the context of the Congreso de Métodos Numéricos em Engenharia 2011 (Coimbra, 14-17/6/2011), three Special Sessions on “Estabilidade e Comportamento Não Linear de Estruturas Metálicas”.

B.4 Dinar Camotim co-organised (within the Control Group of the ASCE EMI Stability Committee, formed also by Noël Challamel, Pizhong Qiao, Yang Xiang and Jifeng Xu), in the context of the 2012 Joint Conference of the ASCE Engineering Mechanics Institute and 11<sup>th</sup> ASCE Joint Specialty Conference on Probabilistic Mechanics and Structural Reliability (South Bend, 17-20/6/2012), a Mini-Symposium on “Stability of Solids and Structures”, which comprised three sessions.

B.5 Dinar Camotim and Cilmar Basaglia co-organised, in the context of the 11<sup>th</sup> International Conference on Computational Structures Technology (Dubrovnik, 4-7/9/2012), six Special Sessions on “Stability, Non-Linear Behaviour and Design of Steel Structures Stability”.

B.6 Nuno Silvestre co-organised (together with Leroy Gardner), in the context of the 8<sup>th</sup> Euromech Solid Mechanics Conference (Graz, 25-28/7/2012), a Mini-Symposium on “Stability and Non-Linear Behaviour of Steel Structures”, which comprised four sessions.

B.7 Dinar Camotim and Rodrigo Gonçalves co-organised (together with Zusana Dimitrovová), in the context of the 6<sup>th</sup> European Congress on Computational Methods in Applied Sciences and Engineering (Vienna, 10-14/9/2012), a Mini-Symposium on “Advanced Beam Models”, which comprised four sessions.

B.8 Dinar Camotim co-organised (together with Noel Challamel, Pizhong Qiao, Yang Xiang and Jifeng Xu), in the context of the 2013 ASCE Engineering Mechanics Institute Conference (Evanston, 4-7/8/2013), a Mini-Symposium on “Stability of Solids and Structures”, which comprised three sessions.

B.9 Dinar Camotim and Cilmar Basaglia co-organised, in the context of the Congreso de Métodos Numéricos en Ingeniería 2013 (Bilbao, 25-28/6/2013), two Special Sessions on “Estabilidade e Comportamento Não Linear de Estruturas Metálicas”.

B.10 Dinar Camotim and Cilmar Basaglia co-organised, in the context of the 5<sup>th</sup> International Conference on Structural Engineering, Mechanics and Computation (Cape Town, 2-4/9/2013), five Special Sessions on “Steel Structures: Stability, Strength and Design”.

B.11 Dinar Camotim and Rodrigo Gonçalves co-organised, in the context of the 11<sup>th</sup> International Conference on Vibration Problems (Lisboa, 9-12/9/2013), a Mini-Symposium on “Advanced Beam Models”, which comprised two sessions.

B.12 Dinar Camotim and Rodrigo Gonçalves will co-organise (together with Zusana Dimitrovová), in the context of the Joint 11<sup>th</sup> World Congress on Computational Mechanics and 5<sup>th</sup> European Conference on Computational Methods (Barcelona, 20-25/7/2014), a Mini-Symposium on “Advanced Beam Models”.

## **M. Awards and Honours**

M.1 In 2010, Dinar Camotim received the “Shortridge Hardesty Award” from the American Society of Civil Engineers (ASCE – EUA), “*in recognition of sustained and substantial contribution to the field of structural stability during his career of active teaching and research*”.

M.2 In 2010, Dinar Camotim was invited to deliver a Keynote Lecture at the International Colloquium on Stability and Ductility of Steel Structures (Rio de Janeiro, 8-10/9). The lecture title was “Latest

Developments in the GBT Analysis of Thin-Walled Steel Structures” (publication D.3) and the work was co-authored by Cilmar Basaglia, Rui Bebiano, Rodrigo Gonçalves and Nuno Silvestre.

M.3 In 2010, Dinar Camotim was invited to deliver a Review Lecture at the 10<sup>th</sup> International Conference on Computational Structures Technology (Valência, 14-17/9). The lecture title was “Numerical Analysis of Thin-Walled Structures Using Generalised Beam Theory (GBT): Recent and Future Developments” (publication A.1) and the work was co-authored by Cilmar Basaglia, Nuno Freitas Silva and Nuno Silvestre.

M.4 In 2010, Rui Bebiano, Nuno Silvestre and Dinar Camotim received the “Prémio Ferry Borges” from the Associação Portuguesa de Engenharia de Estruturas (Portugal), which distinguishes the best journal paper with a Portuguese co-author published in 2008 or 2009. The paper title is “Local and Global Vibration of Thin-Walled Members Subjected to Compression and Non-Uniform Bending” and was published in the Journal of Sound and Vibration (volume 315, issue 3, pages 509-535, 2008..

M.5 Since January 2012, Dinar Camotim is Associate Editor (for “Metal Structures”) of the Journal of Structural Engineering (American Society of Civil Engineers – ASCE, EUA).

M.6 In 2012, Dinar Camotim was invited to deliver a Keynote Lecture at the 7<sup>th</sup> International Conference on Advances in Steel Structures (Nanjing, 14-16/4). The lecture title was “Behaviour and Design of Thin-Walled Angle Columns: Geometrical Simplicity vs. Structural Complexity” (publication D.25) and the work was co-authored by Pedro Borges Dinis and Nuno Silvestre.

M.7 In 2012, André Graça received an Honorable Mention from the Structural Stability Research Council (SSRC – EUA), in the context of the “2012 Vinnakota Award”, intended to distinguish the best article presented by a graduate student at the “SSRC 2012 Annual Stability Conference”, which took place in Grapevine (Texas), on 17-21 March, 2012. The paper has the title “GBT-Based Analysis of Elastic-Plastic Thin-Walled Members” (publication D.30) and was co-authored by Cilmar Basaglia, Dinar Camotim and Rodrigo Gonçalves.

M.8 In 2012, Nuno Silvestre acted as Member the Jury in the defence of a Ph.D. thesis in Civil Engineering, at the Technical University of Denmark. The title of the thesis was “Distortional Mechanics of Thin-Walled Structural Elements”.

M.9 In 2012, Pedro Natário received the “Dr. Rik Heslehurst Best Paper Award” from the Scientific Committee of the 6<sup>th</sup> International Composites Conference (Melbourne,

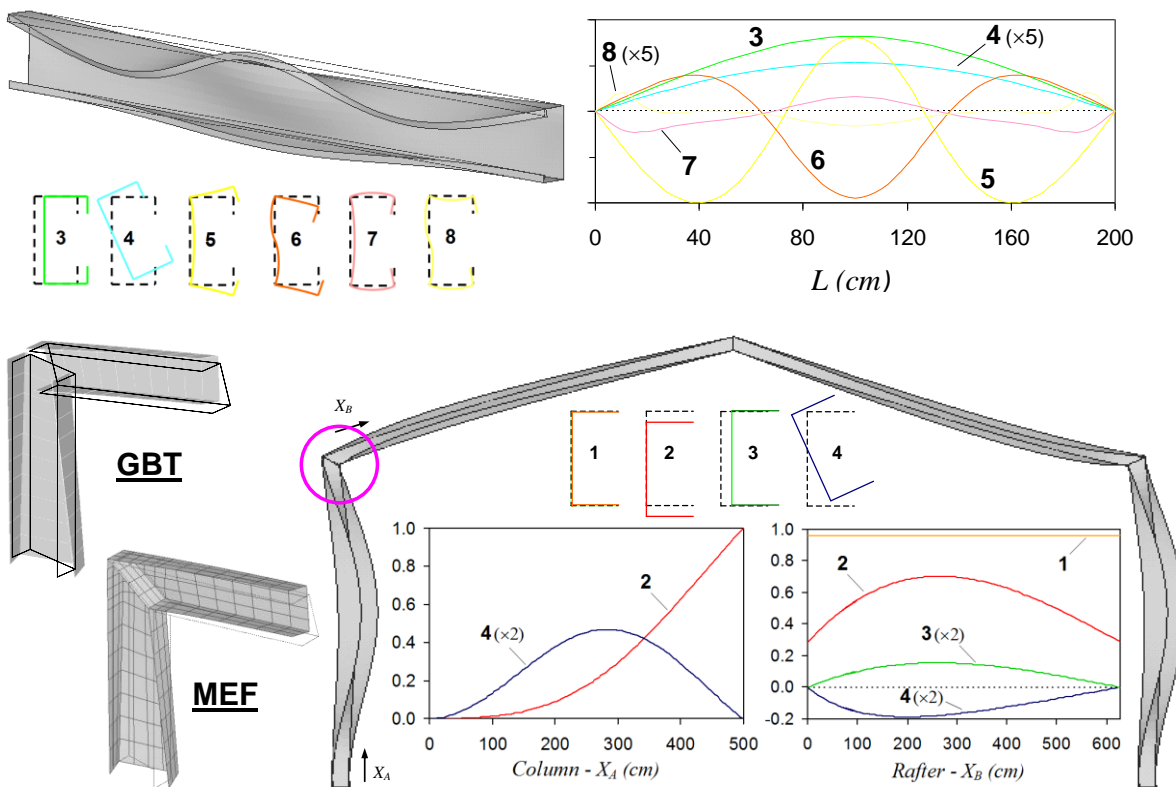
14-16/11), which distinguished the best article presented at that conference in the area of “Civil Infrastructure”. The paper has the title “Analysis of Web Crippling of LiteSteel Beams with CFRP” (publication D.41) and was co-authored by Nuno Silvestre, Dinar Camotim and Xiao-Ling Zhao.

M.10 In 2012, Dinar Camotim was invited to deliver a Keynote Lecture at the 6<sup>th</sup> International Conference on Coupled Instabilities in Metal Structures (Glasgow, 3-5/12). The lecture title was “On the Behaviour, Failure and Direct Strength Design of Slender Thin-Walled Steel Structural Systems” (publication D.44) and the work was co-authored by Cilmar Basaglia.

M.11 In 2013, Miguel Abambres received the “2013 Vinnakota Award” from the Structural Stability Research Council (SSRC – EUA), which distinguished the best article

presented by a graduate student at the “SSRC 2013 Annual Stability Conference”, which took place in St. Louis (Missouri), on 16-19 April, 2013. The paper has the title “GBT-Based Analysis of Elastic-Plastic Thin-Walled Members” (publication D.48) and was co-authored by Dinar Camotim and Nuno Silvestre.

M.12 In 2013, Dinar Camotim was invited to deliver a Keynote Lecture at the 6<sup>th</sup> International Conference on Coupled Instabilities in Metal Structures (Cape Town, 2-4/9). The lecture title was “Local-Distortional Interaction in Cold-Formed Steel Columns: Non-Linear Behaviour, Strength and DSM Design” (publication D.56) and the work was co-authored by Pedro Borges Dinis, Ben Young and Nuno Silvestre.



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**Página web:**

# Protection of Reinforced Concrete Structural Elements Strengthened with CFRP Composite Systems – CARBOFIRE

PTDC/ECM/118271/2010

**KEY WORDS:** CFRP, strengthening, fire behaviour, fire protection

**PROMOTING INSTITUTION(S):** IST-ICIST

**PARTNER INSTITUTION(S):** Universidade de Coimbra, Laboratório Nacional de Engenharia Civil

**PERIOD:** 15-03-2012 to 14-03-2015

**FINANCING (€):**144,180.00€

**IST/ICIST:** 111,003.64€

**COORDINATOR(S):** João Ramôa Correia (ICIST-IST)

**RESEARCHERS AND COLLABORATORS:** Carlos Tiago, Jorge Alfaiate, Fernando Branco, Eduardo Júlio e João Teixeira de Freitas

## SUMMARY

This project addresses the fire behaviour of reinforced concrete (RC) structural elements strengthened with carbon fibre reinforced polymer (CFRP) systems, with the purpose of developing fire protection solutions that enable extending their structural use in buildings. The study focus on (i) the thermophysical and thermomechanical properties of the strengthening system materials, (ii) the mechanical behaviour of CFRP-concrete interfaces at elevated temperature, and (iii) the fire resistance properties of CFRP-strengthened RC members and the effects of different fire protection systems on those properties.

CFRP strengthening systems offer several advantages when compared to traditional solutions in what concerns strength, self-weight and durability. However, there are well-founded concerns with the fire behaviour of CFRP systems, namely for building applications. In fact, the strength, stiffness and bond properties of FRPs are severely deteriorated at moderately elevated temperatures (65-120°C).

This issue, already reflected in design recommendations but yet to be addressed in a comprehensive manner, has hampered the widespread use of CFRP systems in buildings. The few studies that have addressed this subject suggest that adequate fire protection systems need to be developed to allow extending the structural use of CFRP systems in buildings. Moreover, the analysis of the literature shows that the effort of adapting the available FE codes to model the fire response of CFRP-strengthened RC members may justify the development of special-purpose tools to overcome difficulties on the implementation of conventional FEs,

namely in what concerns the sensitivity of the solutions to the variation of the properties of the CFRP system (with temperature and time) and particularly those of the CFRP-concrete interface.

This project will assess the effectiveness of different fire protection systems in extending the fire endurance of RC members strengthened with CFRP systems, externally bonded or near surface mounted. In particular, one aims at evaluating the effect of applying thick insulation on the anchorage zones, a procedure that proved to be very effective in preliminary studies developed by the proponents and that may lead to considerable cost-savings in fire protection systems.

A comprehensive experimental study of the CFRP strengthening and fire protection materials will be performed including (i) dynamic mechanical analyses and thermogravimetric and differential scanning calorimetry tests; (ii) bond tests on CFRP-strengthened concrete blocks at varying temperature; (iii) full-scale fire resistance tests on CFRP-strengthened RC beams, with and without different fire protection systems.

The numerical modelling methodology comprises three stages of development: (i) an improved FE model simulating the nonlinear thermochemical (TC) problem, based on the independent approximation of the temperature and material volume ratio fields; (ii) a FE thermomechanical (TM) model of the physically and kinematically nonlinear response of CFRP-strengthened RC members, that explicitly includes the temperature dependent constitutive relationships of the materials and the interface; (iii) a coupled TC and

TM model of the structural response under fire conditions.

The assessment of the performance of innovative fire protection systems for CFRP-strengthened RC members is the main goal of this project. Such systems should extend the structural use of CFRPs in buildings. The numerical models to be developed and validated with experiments results will allow the simulation of

the fire behaviour of strengthened members with arbitrary cross-section and different fire protection systems, and provide thus a very useful tool for design. A user's manual will be prepared, allowing the fire protection design for building applications and recommending construction procedures and technical specifications for the solutions to be developed.

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# EELWAC - Durability and lifetime of more energy efficient structural lightweight aggregate concrete

PTDC/ECM-COM/1734/2012

**KEY WORDS:** Structural lightweight aggregate concrete, Durability, Energy efficiency, Lifetime

**PROMOTING INSTITUTION(S):** IST-ICIST

**PARTNER INSTITUTION(S):** Nome (xxx/xxx/UTL)

**PERIOD:** 27-06-2013 to 27-06-2015

**FINANCING (€):** 162083.00

**IST/ICIST** 162083.00

**COORDINATOR(S):** José Alexandre Bogas

**RESEARCHERS AND COLLABORATORS:** Maria G. Gomes, António Rodrigues, António Costa, Ana P. F. Pinto, Augusto Gomes

## SUMMARY

The main purpose of this project is to characterize the durability and thermal performance of a more energy efficient structural lightweight concrete (LWAC) for building structures. This project aims at characterizing the durability of LWAC produced with different types of lightweight aggregates (LWA) and taking into account the most types of binders defined in EN 197.

The objective is to define the recommended guidelines for the production of durable LWAC in different exposure environments with minor reservations on their expected performance. This project also aims to define new structural solutions with lower heat losses by thermal bridges and, hence, avoiding some construction damage due to moisture.

Although LWAC in buildings has more than half a century, its research has been intensified in the last 20 years, especially after the technological development of high performance concrete. However, there are still gaps in our knowledge of the properties of LWAC. First, LWAC properties can vary depending on the type of LWA. Most studies are limited to a small number of compositions with a given type of LWA for a narrow range of density and strength classes. Their validity is therefore questionable.

In terms of durability, knowledge is even less consolidated. Thus far, only a few studies have been published concerning the durability performance and lifetime design of LWAC, especially based on different cementitious materials for different exposure environments.

Although some work has been done in our department in recent years, more investigation is needed in order to measure and define the main parameters governing the deterioration mechanisms and their differences with regard to NWC.

Standard prescribed compositions for a required lifetime are usually poorly substantiated. In general, the strategy is to simply adopt conservative values based on the relative performance of LWAC to that of NWC. Moreover, contrary to what happens in NWC, the durability of LWAC should not be characterized as a function of its mechanical strength, as suggested by standards. Another problem is that the durability of LWAC depends on the composition of concrete and the associated transport mechanism.

Traditionally, the durability is roughly considered by the main standards. In general, this requirement is simplified by prescribing some concrete composition limits, which depend on the exposure conditions (e.g., concrete cover, w/c ratio, type and cement content, strength). This philosophy is adopted in the main European standards and respective national annexes (EN 206, Eurocodes). However, this normalization was only structured for NWC. Therefore, it is also necessary to adjust it for LWAC.

The main purpose of this project is to characterize the LWAC durability and its lifetime performance concerning some of the main deteriorating mechanisms in concrete structures (chloride penetration, carbonation, sulfate attack). The durability of LWAC is studied taking into account different cementitious materials and exposure

conditions. The deterioration mechanisms are modelled and lifetime semi-probabilistic and probabilistic estimates are performed [4, 5]. As a result, new tables will be built with recommended

composition limits for LWAC with different types of binders, as it is suggested for NWC in EN 206 and LNEC specification E464.



**Example of one type of the five lightweight aggregates used**



**Concrete slabs exposed to chloride attack in severe real environments**

In addition, an in situ experimental program should be conducted in order to validate the laboratory work. Useful data is expected to be obtained from different natural exposure conditions, such as in marine and urban environment.

This research project also aims to evaluate the thermal insulation properties of innovative and better energy efficiency solutions produced with durable LWAC. Recommended compositions based on the study of LWAC durability will be characterized, through experimental and numerical studies, in terms of thermal conductivity and characteristic heat loss coefficients associated with thermal bridges, which are important parameters for assessing building energy efficiency. This study aims to match the advantages of reduced weight and better thermal performance of

LWAC to the durability requirements defined in this work. This is of major relevance, as it will provide the concrete industry with feasible, durable and more energy efficient systems for building envelopes.

Most of the research team has experience in the theme of this project, having dedicated the last 5 years to the study of LWAC. It has been developed a vast work in the production, formulation and characterization of LWAC with different strength and density classes. This comprehensive investigation has culminated with a PhD work concluded in 2011 [2].

To the best of the team members' knowledge, such a comprehensive study on the durability of LWAC has never been done. In sum, this research project is expected to contribute for the specification of durable LWAC as a more efficient alternative to NWC

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# Mechanical and durability performance of concretes made with fine recycled aggregates from construction and demolition waste from Portuguese recycling plants

**PTDC/ECM/108682/2008**

**KEY WORDS:** Fine recycled aggregates; Concrete; Sustainability in construction, Construction and Demolition Waste

**PROMOTING INSTITUTION(S):** IST-ICIST

**PARTNER INSTITUTION(S):** Centro de Recursos Naturais e Ambiente (CERENA/IST/UTL)

**PERIOD:** 01-04-2010 to 31-09-2013

**FINANCING (€):** 150.953

**IST/ICIST:** 150.953

**COORDINATOR(S):** Jorge de Brito

**RESEARCHERS AND COLLABORATORS:** António Costa; Luís Evangelista; Teresa Carvalho; Miguel Santos; Paulo França; Rui Isidoro

## **SUMMARY**

According to UNFPA, in 2008 more than half of the world's population lives in cities, setting a new record in the history of Mankind, and in 2030 that number will reach about 5 billion people. Human migration to urbanized areas helps world development but the increasing pressure on the cities' urbanized areas leads to an increase in buildings, with an increase in the construction and demolition waste produced, with obvious negative environmental impacts. It is estimated that between 3 and 6 million tons of CDW are produced in Portugal every year, with a tendency to increase, since Portugal is starting to renew its housing park, contrasting with the traditional trend of creating new buildings.

Among the different measures available to process CDW, its recycling is one of the most interesting because it leads to a reduction of natural raw materials extracted, reducing the consequent environmental impacts associated, and it significantly reduces the amount of CDW taken to landfill.

In concrete production, it is widely accepted that part of the coarse natural aggregates (CNA) can be replaced by coarse recycled aggregates (CRA), without drastically reducing its properties. However, the same does not apply to fine recycled aggregates (FRA) use, in replacement of fine natural aggregates (FNA), since it is claimed that the environmental advantages achieved by using FRA do not compensate the significant reduction of performance of these concretes. The main cause that is presented for such detrimental effect lies on the fact that FRA have far greater porosity and water absorption, therefore

inducing worse behavior to the concretes made with them.

On the other hand, some recent investigations have proven differently, suggesting that fine recycled aggregates concrete (FRAC) is a viable product, both in terms of mechanical and durability behavior. The extraction of FNA has considerable environmental costs, either by dredging river or sea beds or by crushing natural stone. Dredging FNA at river or sea beds causes changes in the river's water flow, leading to erosion on the downstream shores. Dias (2005) studied the impact of river bed dredging activity on the main Portuguese rivers, having concluded that the activity should immediately cease, with the exception of the dredge required for naval transports. The Sandpit project (EVK3-CT-2001-00056) developed to estimate the impacts of massive North Sea's sea bed sand extraction on the local and regional ecosystems, alerted to the fact that this activity could affect tide and current wave on the areas exploited. As an alternative to sand extraction, there is the possibility of crushing rocks to create sand artificially. This process also has significant negative environmental impacts, because it uses natural stone, a limited abiotic resource, which could have been used for "nobler" purposes, and it uses natural resources and produces emissions during the crushing process.

Considering these factors, the possibility of using FRA on concrete production has two clear advantages: (a) it allows reducing natural resource consumption, as well as the associated environmental impacts inherent to the extraction or production activity; this happens 34 because FRA are automatically generated with

crushing of CDW, being a by-product of the process; (b) it allows reducing the quantities of dumped materials, generating an increase of capacity of deposit of non recyclable or hazardous materials.

Taking all these factors into account, the main purpose of this research project, totally innovative in Portugal, is to evaluate, as thoroughly as possible, the properties of concretes made with FRA created from CDW gathered at Portuguese recycling plants. In order to do this, it will be required that a state-of-the-art research is conducted, followed by a field survey of the FRA produced from CDW at Portuguese recycling plants, which will allow classifying and characterizing the different types of FRA produced. Using samples from these FRA, an extended campaign is to be made, in which several families of FRAC, considering different type of FRA and different replacement ratio of FNA for

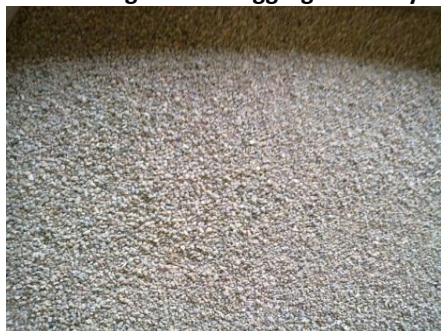
FRA, will be tested. These concretes will be analyzed in terms of mechanical, rheological and durability properties and comparisons between their behavior and that of reference concretes, made solely of natural aggregates, will be conducted.

Finally, based on the conclusions previously drawn, it is expected that a proposal of a new guide for the use of FRA on concrete production is published, considering the type of FRA used, the nature of concrete to be produced and its environmental exposure.

The large experience of the research team, and of the principal researcher in particular, in the field of the use of CRA and FRA in the production of structural concrete, demonstrated by a significant number of international publications, guarantees the efficacy of the methodology proposed.



**Various stages of the aggregates' recycling process.**



**Post-treated recycled aggregates.**

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# High performance recycled aggregates concrete for the precast industry

PTDC / ECM / 118372 / 2010

**KEY WORDS:** Recycled aggregates; Precast industry; Concrete; Excellent performance

**PROMOTING INSTITUTION(S):** IST-ICIST

**PERIOD:** 21-03-2012 to 20-03-2015

**FINANCING (€):** 182,630.40

**IST/CIST (€):**182,630.40

**COORDINATOR(S):** Jorge de Brito.

**RESEARCHERS AND COLLABORATORS:** Luís Evangelista; Pedro Silva; Diogo Pedro

## SUMMARY:

This project aims at evaluating the feasibility of reintroducing recycled concrete aggregates in the precast industry. The properties of concrete incorporating recycled aggregates (fines and coarse - FRA and CRA) from crushed precast elements will be evaluated and the constitutive laws allowing the future use of these aggregates in the industrial process with no reservations on the expected performance will be established.

The precast industry is a construction sector in clear expansion worldwide since it allows increasing the pace of construction processes, guaranteeing higher quality levels in the finished elements, both in terms of quality of the materials used and of structural reliability. The strict quality control system of these firms leads to the production of significant quantities of debris from rejected products. These elements have a great recycling potential given the quality of concrete employed. The different tasks proposed lead to the establishment of a solid and innovative scientific basis, supported by experimental analysis and mathematical formulation, that allows the precast industry to use without restrictions the most part of the self-generated waste.

For the RA used to have quality adequate to the technical demands that the precast industry requires it is intended with this Project to optimize the comminution process used to produce RA. Consequently the performance (here always perceived as mechanical and durability-related) of concrete made with CRA produced using the current crushing process of RA (primary crushing only) will be evaluated and compared with that of concrete with AGR obtained using a 2 stage comminution process (primary and secondary crushing), similar to the one used currently for natural stone aggregates.

Using the optimized comminution method from the previous stage the goal is to evaluate the capacity to produce concrete with a pre-determined performance

(in terms of mechanical strength) incorporating varying contents of RA (FRA and CRA) obtained from a source concrete (SCo) with a performance level equal to the target. The verification of this capacity to self reproduce will be made for three strength levels, from concrete with low mechanical performance (20-30 MPa) to concrete with very high mechanical performance (60-70 MPa). Based on the results obtained one of the SCo's tested will be selected to perform a complementary experimental campaign where the potential of the FRA and CRA from that SCo to produce concrete of any strength level, with special emphasis on high-performance concrete (HPC), will be evaluated.

The production of precast concrete elements frequently resorts to self compacting concrete (SCC) instead of conventionally cast concrete since it eliminates the need of vibrating mechanical devices that are expensive and error-prone. In the project, the performance of SCC made with FRA and CRA (with various replacement ratios) will be evaluated.

In a considerable percentage of structural precast elements, HPC is used allowing slender and lighter solutions and facilitating their transportation and handling. The project will also contemplate a research stage in which the intention is to produce and characterize HPC (SCC or not) with compressive strength over 90 MPa, maximizing the use of FRA and CRA, but without increasing the environmental impact of RAC as compared to that of conventional HPC, e.g. by using superplasticizers, special cements or additions.

Finally, in order to allow RA to be used with no theoretical restrictions by the precast industry, and taking into consideration that RAC mechanical and rheologic properties may be different, is it envisaged to establish design rules adapted from the most recent codes, namely the Fib Model Code 2010.

The main objective of this project is providing the precast industry with an internationally innovative way of processing and adding value to the waste produced,

minimizing the consumption of natural resources and consequently significantly decreasing the

environmental impact.



### Different stages of the project

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# NANORENDER - Performance of silica nanoaerogel-based renders

PTDC/ECM/118262/2010

**KEY WORDS:** Aerogel, Renders, Performance, Nanotechnology

**PROMOTING INSTITUTION(S):** IST-ICIST

**PARTNER INSTITUTION(S):**

**PERIOD:** 20-03-2012 to 19-03-2015

**FINANCING (€):** 131.532

**IST/ICIST** 131.532

**COORDINATOR(S):** Inês Flores-Colen

**RESEARCHERS AND COLLABORATORS:** Jorge de Brito, José Dinis Silvestre, António Moret Rodrigues, Maria Glória Gomes, Albano Neves Sousa, António Soares, Maria Júlio

## SUMMARY

The aim of this project is to investigate the use of silica-based aerogels in coating mortars (renders) in order to formulate improved-performance renders from a thermal, acoustic and environmental point of view, for application in building walls.

In the last years the construction industry has undergone profound changes triggered by the growing concerns with sustainability, coupled with more demanding energy and environmentally wise European directives (Directives 2002/91/CE from 16 December, and 2010/31/UE from 19 May). On the other hand Portuguese legislation in terms of energy performance of buildings (Decree-Laws No. 78/2006, 79/2006 and 80/2006) has encouraged the search for new products and construction systems with a better hygrothermal performance. In this context, the development of new coating solutions has significantly increased recently, aiming at reducing the incorporation of processed raw materials and energy and the environmental impact from the production, use and final destination of the product at the end of its service life.

The renders market (the most used external covering solution in Portugal, with around 62% of all types, from a universe of 3160043 buildings) has increasingly responded to the integration of more sustainable strategies. The use of ready-mixed mortars, with controlled compositions of aggregates, admixtures and additions, has been improving the in-service performance of these products, minimizing degradation phenomena (due mostly to water entry). Recent studies on thermal and acoustic insulation mortars most often at the research level yet aim to contribute to a better global performance of walls in new and rehabilitated buildings, by minimizing energy consumptions within an environmental and economic

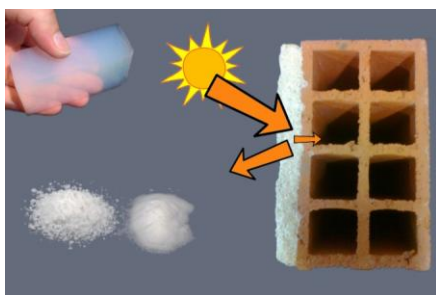
strategy.

Nanotechnology in the construction industry has allowed acting at the microstructural level of conventional materials, improving their physical and chemical properties. Aerogels come into this equation as very porous mineral materials composed mostly of air that can be produced as powder or grain-shaped leading to significant improvements of the products they incorporate. As a matter of fact the potential of aerogels is consensual in the scientific/technical medium because they are extremely light (density below  $500 \text{ kg/m}^3$ ) and have a high thermal (thermal conductivity down to  $0.01 \text{ W/m.K}$ ) and acoustic (acoustic impedance below  $106 \text{ kg/m}^2.\text{s}$ ) performance. Their large-scale use in construction, namely in the thermal and acoustic insulation area, is presently possible since the high costs associated with their production have been overcome.

In this project, named NANORENDER, the goal is to use as aggregate in mortars a silica or silica/latex-based aerogel, obtained from safer and less costly processes, already tested and patented by members of the research team. This change may lead to economically competitive mortars, with improved hygrothermal, mechanical, physical-chemical and environmental performance, a thickness closer to that of current mortars even though compatible with the growing sustainability demands in construction, and simultaneously complying with the requisites of European norm EN 998-1 that is the basis of CE marking of coating mortar products.

Therefore, the composition and size grading of the aerogels to be used will be optimized and various aerogel-based mortar mixes will be studied, with various changing parameters such as the aggregates content, the water/binder ratio, and the admixtures

and additions content, in order to analyze the performance properties in mortar specimens. To evaluate the behaviour of renders various characterization tests of the performance of mortars applied in brick models and later on in prototype wall panels will be made, using different values of the mortar's thickness. Finally, the project comprises a theoretical simulation to predict the performance of renders applied on building walls, with different backgrounds and in in-service conditions, in order to characterize and quantify the economic, environmental, thermal and acoustic benefits that nanoaerogel-based renders can bring to the construction industry vis-à-vis conventional renders. The main objective of this project is thus to study competitive alternatives in the national and international markets that use advanced technology (nanotechnology-related) and can significantly improve the performance of conventional renders (traditional or ready-mixed), cement-based and more compact/resistant, that are currently applied in building walls.



Team members have scientific background on synthesis and characterization of nanostructured and new hybrid materials (CQFM, such as hybrid silica /latex nanoaerogel production process, developed in FCT project AIRSILTEX (POCTI/CTN/33487/99), that led to a national patent (PT-103257-05/04/2005) and international extensions (PCT/PT2006/000010-04/04/2006; AU 2006231371-12/10/2006; CA 2604802 (A1)-12/10/2006; JP 2008537570-18/09/2008; BR 200607020-04/08/2009; US 7737189 B2-15/06/2010), <http://cqfm.ist.utl.pt/Projects.html>. The team has performed numerical/experimental approaches to study the thermal and acoustical performance of walls components (ventilated cavity wall in a FCT project POCTI/36017/ECM/2000; double skin façade part of Annex 44 of the International Energy Agency (IEA)), providing results with application in buildings design in terms of indoor comfort and air quality requirements accomplishment.

## DELIVERABLES

### Papers in international journals

Júlio, M.; Ilharco, L. – “Superhydrophobic hybrid

aerogel powders from waterglass with distinctive applications”, *Microporous and Mesoporous Materials*, 199 (2014), 29-39.

Soares, A.; Julio, M.; Flores-Colen, I.; Ilharco, L.; de Brito, J.; Gaspar Martinho, J. – Water-resistance of mortars with lightweight aggregates, *Special Issue Key Engineering* (selected from CLB-MCS conference).

### Papers in national journals

Flores-Colen, I.; Soares, A.; Brito, J. de: "A Nanotecnologia aplicada às argamassas de revestimento", *Revista Internacional Construlink*, Nº 34, Vol 11, pp. 42-51, Outubro 2013.

### Communications in conferences

Júlio, M. F.; Ilharco, L. M.: “Sodium silicate based aerogel powders prepared at atmospheric pressure: Influence of the synthesis parameters on the physicochemical properties”, XVII International Sol-Gel Conference, 2013, Madrid, 25-30 Agosto.

Júlio, M. F.; Ilharco, L. M.: “Hydrophobic Silica Based Aerogels Prepared at Atmospheric Pressure”, 1st Cluster Workshop in Materials and Nanotechnology, 4-6 December 2013, IST, Poster.

Vale, H.; Melo, H.; Soares, A.; Flores-Colen, I.; Glória Gomes, M. (2014) - “Performance of industrial thermal insulation renders”. In 9th International Masonry Conference. Guimarães. (CD).

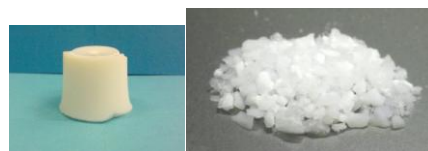
Soares, A.; Flores-Colen, I.; Brito, J. de (2014) - “Nanorenders on buildings facades: technical, economic and environmental performance”. In XIII International Conference on Durability of Building Materials and Components (DBMC). São Paulo (CD).

Júlio, M. F.; Ilharco, L. M.: - Hybrid aerogel powders prepared from waterglass at atmospheric pressure - 4th Portuguese Young Chemists Meeting, 29th to 1st may 2014, Coimbra.

### Completed Theses

Vale, H. (2014) - Características mecânicas de argamassas de desempenho melhorado, IST.

Melo, H. (2014) - características físicas de argamassas de desempenho melhorado, IST.



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# UNPLACE- A museum without a place: intangible museography and virtual exhibitions

Ref. FCT: EXPL/CPC-EAT/1175/2013

**KEY WORDS:** Online museums and exhibitions; Web art; Virtual communities and architecture; Intangible heritage and museography

**PROMOTING INSTITUTION(S):**

Associação do Instituto Superior Técnico para a Investigação e o Desenvolvimento (IST-ID)

**PARTNER INSTITUTION(S):**

Faculdade de Ciências Sociais e Humanas – Universidade Nova de Lisboa  
Programa Gulbenkian Próximo Futuro - Fundação Calouste Gulbenkian, Lisboa

**PERIOD:** 01-03-2014 to 28-02-2015

**FINANCING (€):** 46147,00                      **IST/ICIST** 27306,00

**COORDINATOR(S):** Helena Barranha (ICIST – IST)

**RESEARCHERS AND COLLABORATORS:**

**SUMMARY**

Over the last two decades, museums have become increasingly influential agents in a mediatized and globalized world, strongly impacting fields as different as tourism, culture or city planning. At the same time, a large number of internet-based projects involving virtual museums and exhibitions has also been growing. As an invaluable communication tool, the Internet shapes, nowadays, a challenging new territory for museums, providing new possibilities for curatorship, architecture and exhibition design projects. Concurrently, its effects on art practices can also be decisively assessed by recent movements like Digital Art or Web Art.

While these virtual projects seem to fruitfully embrace immateriality as an operative and creative notion, many of them further configure a paradoxical movement. In fact, and surprisingly enough, most cases fail to propose utterly innovative works or environments, as they simply tend to reproduce prevailing models from the material world: digitizing existing collections and duplicating, online, real exhibition spaces.

On the one hand, referential museological institutions worldwide are using digital resources as preferential tools of self-representation. Although museums occasionally promote web-specific projects, they have mostly been interested in expanding and presenting, digitally, their own collections and the activities that take place within their buildings. Key international collaborative ventures, such as the popular Google Art Project, constitute important joint efforts which

highlight the geographical diversity of the world shared heritage while they remain, nevertheless, closely linked to the simulation of pre-existing realities. On the other hand, it can also be verified that even museums which were originally conceived to operate only in cyberspace often replicate architectural models already designed or built in different historical or geographical contexts. Although many scholars have theoretically proposed new conceptual frameworks to deal with the emergence of virtual museographies, concrete examples of digital museums are often not as groundbreaking as expected, and demonstrate, in fact, how strongly traditional stereotypes of museum architecture and design are still dominant in virtual environments.

The investigation of new immaterial paradigms for exhibition architectures and displays seems, then, to be all the more crucial at a time when intangible cultural heritage is increasingly valued and art practices based on digital processes are unprecedentedly present in contemporary culture. Within this context, this research project chiefly aims: (1) to understand the reasons underlying the persistence of actual material references in current projects on virtual museums/exhibitions; (2) to analyze remarkable case studies which effectively succeed to overcome the conventional and tangible references in the field of digital exhibitions. Particular attention will be paid to projects committed to explore participative reception and collaborative platforms for contemporary art.

Finally, this work also proposes (3) to outline alternative guidelines for future developments in the domains of museum architecture and virtual exhibitions. By doing so, it will examine and characterize this specific kind of museography which – despite, and because, of its physical intangibility – can certainly be more accessible than any other form of exhibition. With the involvement of the Next Future Program (Calouste Gulbenkian Foundation), it will be possible to build a network for sharing and discussing innovative concepts and practices, including contributions of artists, curators, designers, architects who will converge virtually, despite their different geographical locations. Furthermore, this platform will be oriented to a wider audience and will configure the

basis for a future exhibition of contemporary art, entirely web-specific. Assuming the complex and contradictory intention of both conserving and promoting immaterial heritage as a distinctive feature of contemporary culture, this project expects to (re)formulate the concept of intangible museography. To this end, the study will focus on the significantly revealing field, at the same time real and virtual, which lies at the technological crossroads of architecture, contemporary art and new media.

For further information, visit the project website: [unplace.org](http://unplace.org)



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**Página web:** [unplace.org](http://unplace.org)

# 3D mapping of suction in soil specimens using relative humidity sensors incorporated inside oedometric cells

EXPL/ECM-GEO/0109/2013

**KEY WORDS:** micro sensors; Soil suction; hydro-mechanical behaviour; laboratory testing

**PROMOTING INSTITUTION(S):** IST-ICIST

**PARTNER INSTITUTION(S):** INESC-MN

**PERIOD:** 01-03-2014 to 28-02-2015

**FINANCING (€):** 49.980

**IST/ICIST:** 37.980

**COORDINATOR(S):** Rafaela Cardoso

**RESEARCHERS AND COLLABORATORS:**

## SUMMARY

An explanatory project is proposed focused on the fabrication and calibration of soil suction sensors for 1mm<sup>3</sup> sampling ranges, aiming a 3D monitoring of soil samples. These miniature sensors are based on humidity sensors designed for small footprint and can offer local information not available by the commercial sensors. The overall goal in this project is to assess their ability to perform suction measurements inside soil specimens during an oedometer test performed under controlled suction.

The study of unsaturated soils is important for several Geotechnical engineering applications, being some of the most important the prediction of deformations caused by wetting or drying, the study of soil-atmosphere interaction and the development of tools to model unsaturated flow of water, gas and contaminants in both liquid and gas phases.

From a constitutive modelling point of view, advances in the research on unsaturated soils behaviour allows defining models for different types of materials, such as rockfill, sands, collapsible soils, non expansive clays and very expansive clays. Nevertheless, mainly in the case of fine soils there are several aspects still under investigation, starting with the definition of effective stresses for unsaturated states and ending with the consideration of electrochemical effects to understand deformation and water retention mechanisms in clays because they are connected with osmotic effects. These reasons justify research on the characterization of the hydro-mechanical coupled behaviour of fine soils and therefore the development of sensors to be placed inside the soil specimens.

During tests in unsaturated soils, so far, current suction measurements are made after sampling the specimens, outside the experimental cells, or suction is applied globally to the specimen during the test by

axis translation, vapour equilibrium, or osmotic solutions. Therefore local effects are unknown, as well as how water flows (suction changes) in response to mechanical loads, or how deformations occur as response to wetting or drying.

There are several sensors that can be used for soil suction measurement, such as tensiometers, psychrometers, electrical resistivity and TDR probes, however their size or suction measurement ranges is not adequate for their installation inside specimens to be tested in standard oedometer and triaxial cells where realistic loading paths can be applied. Some of the most popular soil suction sensors measure relative humidity. The working principles of some these sensors are very similar to those of the relative humidity sensors already available in the market for other applications. These sensors are commercially available however they show similar limitations mainly in size, accuracy or speed of measurement to those observed in soil suction sensors. As an advantage, their measurement range can be larger than that of the sensors used in soils. For this reason the sensors to be developed will be fabricated as commercial sensors but will be adapted to be as small as possible to make the readings in 1mm<sup>3</sup> volume, therefore allowing mapping suction inside specimens made of fine soils.

The tasks predicted in this project include the microfabrication, testing and calibration of the sensors and their incorporation in an oedometer cell to measure suction during an oedometer test or when suction is applied using axis translation technique. The performance of the sensors will be evaluated considering the range of detection of the sensor (linked with the size), range of readings and accuracy in entire measurement range, response time, repeatability and hysteresis when cycles are applied.

The 3D suction sensors prototype and the experimental setup allowing suction measurement and data acquisition during the test are the most important milestones of this project.

To conclude, the existence of such type of sensors will allow fundamental studies in the domain of

unsaturated soils constitutive modelling. However it is believed that the most important practical and industrial contribution of this research will be the possibility to investigate chemo-hydro-mechanical aspects connected to topics traditionally studied in the domain of environmental Geotechnics.

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# Development of a prototype of a pedestrian bridge – PONTALUMIS

ADI 2009/003456 (Innovation Agency)

**KEY WORDS:** GFRP, pultruded profiles, hybrid structure, pedestrian footbridge

**PROMOTING INSTITUTION(S):** IST-ICIST

**PARTNER INSTITUTION(S):** Universidade do Minho, Alto Perfis Pultrudidos, Lda.

**PERIOD:** 2008 to 2012

**FINANCING (€):**501,214.50€

**IST/ICIST:** 112,695.51€

**COORDINATOR(S):** Fernando Branco (ICIST-IST)

**RESEARCHERS AND COLLABORATORS:** João Ramôa Correia, João Ferreira

## SUMMARY

The objective of this project is to develop a prototype of a pedestrian bridge to be installed over any type of transportation axes.

The conceived bridge deck presents a hybrid cross-section, constituted by a glass fibre reinforced polymer (GFRP) pultruded tubular profile connected, at the level of the top flange, to a compressive layer of engineered cementitious composite material (ECC). The GFRP profile is prestressed with fibre reinforced polymer (FRP) bars, placed at the level of the bottom flange, allowing to fulfil deformability requirements. The connection between the ECC layer and the GFRP profile is assured by a layer of epoxy adhesive and steel bolts. To avoid shear failure of the GFRP profile at the support zones, an innovative process is applied, combining the strength and fluidity characteristics of ECCs.

This well balanced structural system can retrieve all the high potentialities of the involved materials. The ECC layer increases significantly the stiffness of the

structural system, since it is constituted by a material of high strength, ductility and energy absorption capacity. Since the reinforcement system of this ECC thin plate is composed of discrete fibres, and ECC has self-compacting requirements, the manufacture of these plates is simple and faster, if a pre-fabrication line and pre-fabrication practices are used. A pre-fabrication line is also used to assemble to the GFRP profiles and ECC plate, using an automaton process to build the pedestrian bridge structure in a competitive and high quality control framework.

The main advantages of the new pedestrian bridge to be developed within this project are light-weight, quick erection, electromagnetic insulation properties, improved durability and low maintenance requirements during the service life.

This project will receive the contributes of the most recent research developments at the groups of IST and UM on the use of GFRP profiles, hybrid concrete-GFRP systems, ECCs and composite materials.



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# Development of a prototype of an emergency house in composite materials – CLICKHOUSE

ADI 2014/038967 (Innovation Agency)

**KEY WORDS:** GFRP, prefabricated house prototype, disaster zones, temporary shelters

**PROMOTING INSTITUTION(S):** IST-ICIST

**PARTNER INSTITUTION(S):** Universidade do Minho, Alto Perfis Pultrudidos, Lda.

**PERIOD:** 01-03-2014 to 30-06-2015

**FINANCING (€):** 952,375.30€

**IST/ICIST:** 219,695.38€

**COORDINATOR(S):** João Ramôa Correia (ICIST-IST)

**RESEARCHERS AND COLLABORATORS:** Fernando Branco, João Ferreira, Nuno Silvestre, José Barreiros Ferreira, Maria da Glória Gomes, Albano Neves e Sousa

## SUMMARY

The main aim of ClickHouse is the development of a prefabricated house prototype (with 36 m<sup>2</sup> and about 2.5 ton) for disaster zones, situations of emergency housing, construction sites and/or temporary shelters, using advanced composite materials.

When comparing to the classic solutions in the market, the constructive system should guarantee, at a competitive cost, a better performance regarding: (i) lightness; (ii) ease of transportation; (iii) quickness and facility of assembling and disassembling; (iv) possibility/flexibility of reutilization; (v) fulfillment of structural safety and thermal performance regulation requirements and recent international recommendations for this type of housing; (vi) self-sufficiency regarding energy and water supply; and (vii) durability.

The housing structure to be developed is composed of glass fibre reinforced polymer (GFRP) pultruded profiles. The façade and the roof will be made of sandwich panels with outer skins of GFRP and a core

of an insulating material, comprising windows, doors and piping networks. The connections between the panels and the profiles will be achieved by splicing and/or bolting.

The housing will incorporate water, sewage and electricity networks. The sanitation facilities will be conceived in an independent module, attachable to the main module, and containing a water reservoir on the roof of the house. It is also expected to include a system of water collection and the use of photovoltaic panels for power supply.

This project is led by the Portuguese company ALTO, specialist in constructive solutions based on GFRP profiles, in consortium with IST and UM, leaders in GFRP profiles and sandwich panels in composite materials. In order to achieve the proposed goals and innovative features, the consortium has established a methodology based on industrial research and development activities

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# Concretes with recycled aggregates generated from precast elements

**KEY WORDS:** Coarse recycled aggregates; Precasting industry; Full-scale models; Durability; *In situ* testing; Structural behaviour

**Promoting institution(s):** IST-ICIST

**PARTNERS INSTITUTION(S):** Opway

**Period:** 01-06-2012 to 01-10-2013

**FINANCING (€):** 80,500.00

**IST/CIST (€):**80,500.00

**COORDINATOR(S):** Jorge de Brito.

**RESEARCHERS AND COLLABORATORS:** João Gomes Ferreira; Diogo Soares; João Pacheco

## SUMMARY:

The use of recycled aggregates (RA) in concrete is a step towards sustainability, enabling a reduction of the use of natural resources and of the waste produced.

Attention paid to this kind of material increased after WWII, given the urgent infrastructural and housing needs, combined with the quantity of debris generated in some cities damaged by air raids. Hansen (1992) provided a state-of-the-art on RA at the end of the 20<sup>th</sup> century. Presently, the knowledge regarding this material is much more substantial, mostly because the interest in the behaviour of recycled aggregate concrete (RAC) increased, due to social, political and cultural aspects regarding environment protection.

In this context, a study regarding the behaviour of concretes made with incorporation of recycled aggregates generated from the precasting industry was made. These aggregates, due to their origin, have high quality and are expected to be a viable solution in the reduction of the consumption of materials of the construction industry.

The current knowledge regarding the incorporation of recycled aggregates in concrete is mostly focused on the mechanical and durability performance, with relatively few studies regarding the structural behaviour of this solution. Hence, this investigation not only studies mechanical and durability performances of different concrete mixes (within Eurocode 2's C25/30

class) by means of laboratory tests, but also aims at assessing their structural behaviour, by experiments on four full-scale reinforced concrete structures done with the same concrete mixes as the concrete elements done for laboratory testing purposes, namely dynamic characterization tests, vertical load tests and horizontal destructive tests by monotonic loading. Additional, material *in situ* characterization tests (rebound hardness, ultrasonic pulse velocity and compressive strength tests on concrete cores) studied material properties of the concrete structures.

This project's documentation includes the procurement process that led to the recycled aggregates used, the planning of both experimental campaigns (the mechanical and durability performance and the structural behaviour campaign), the definition of the concrete mixes, the design of the structures (complying with the Eurocodes), the execution and analysis of the results of each test done and, by comparison between the performance of the concrete mixes, the effects of the recycled aggregates incorporation in the behaviour of concrete.

In this project, only the coarse fraction of the recycled aggregates obtained was used, since the fine fraction, having a greater amount of attached mortar, has a more detrimental effect on the concrete properties.



Different stages of the project

#### DELIVERABLES

##### Completed Theses

J. Pacheco, "Desempenho de estruturas executadas em betão com agregados grossos reciclados provenientes da indústria de pré-fabricação", Dissertação de Mestrado Integrado em Engenharia Civil, Instituto Superior Técnico, Lisboa, Junho de 2014, 128 p.

D. Soares, "Desempenho de betões com agregados grossos reciclados provenientes da indústria de pré-fabricação", Dissertação de Mestrado Integrado em Engenharia Civil, Instituto Superior Técnico, Lisboa, Julho de 2014, 126 p.

##### Papers in International Journals

Pacheco, J.; de Brito, J.; Gomes Ferreira, J.; Soares, D., "Dynamic characterization of full-scale structures made with recycled coarse concrete aggregates"; *Engineering Structures* (submetido para publicação);

Pacheco, J.; de Brito, J.; Gomes Ferreira, J.; Soares, D., "Vertical load tests of full-scale recycled aggregates concrete structures"; *Journal of Materials in Civil Engineering* (submetido para publicação);

Pacheco, J.; de Brito, J.; Gomes Ferreira, J.; Soares, D., "Horizontal destructive load tests of full-scale recycled aggregates concrete structures"; *ACI Structural Journal* (submetido para publicação);

Soares, D., de Brito, J.; Gomes Ferreira, J. Pacheco, J., "Use of coarse recycled aggregates from precast rejects: mechanical and durability performance"; *Construction & Building Materials* (submetido para publicação);

Soares, D., de Brito, J.; Gomes Ferreira, J. Pacheco, J., "In situ materials characterization of full-scale recycled aggregates concrete structures"; *Construction and Building Materials* (submetido para publicação).

##### Papers in National Journals

Pacheco, J.; de Brito, J.; Gomes Ferreira, J.; Soares, D., "Caracterização Dinâmica de Estruturas à Escala Real Produzidas com Agregados Grossos Reciclados de Betão"; *Mecânica Experimental* (aceite para publicação);

Soares, D.; Brito, J. de; Ferreira, J.; Pacheco, J.: "Utilização de Agregados Grossos Reciclados de Resíduos da Pré-fabricação. Parte I - Programa Experimental,

Apresentação e Análise dos Resultados dos Ensaios aos Agregados”, Betão (aceite para publicação);

Soares, D.; Brito, J. de; Ferreira, J.; Pacheco, J.: "Utilização de Agregados Grossos Reciclados de Resíduos da Pré-fabricação. Parte II - Apresentação e Análise dos Resultados dos Ensaios ao Betão no Estado Fresco e Endurecido”, Betão (aceite para publicação).

#### **Proceedings in National Conferences**

Pacheco, J.; Brito, J. de; Ferreira, J.; Soares, D.: "Caracterização Dinâmica de Estruturas à Escala Real Produzidas com Agregados Grossos Reciclados de Betão”, 9º Congresso Nacional de Mecânica Experimental, APAET, Aveiro, Outubro de 2014.

#### **Internal Reports**

Soares, D.; Pacheco, J.; Brito, J. de; Ferreira, J.: "Aquisição de Elementos de Betão Provenientes da Indústria da Pré-Fabricação”, Relatório da Tarefa 0 do Projecto “Utilização de Resíduos de Betão da Indústria de Pré-Fabricação com Agregados Reciclados”, Relatório ICIST, DTC 09/13, Lisboa, Abril de 2013.

Pacheco, J.; Soares, D.; Brito, J. de; Ferreira, J.: "Projecto das Estruturas a Ensaiar”, Relatório da Tarefa 2.1 do Projecto “Utilização de Resíduos de Betão da Indústria de Pré-Fabricação com Agregados Reciclados”, Relatório ICIST, DTC 10/13, Lisboa, Abril de 2013.

Pacheco, J.; Soares, D.; Brito, J. de; Ferreira, J.: "Ensaio em Estruturas com Agregados Grossos Reciclados”, Tarefa 2 do Projecto “Utilização de Resíduos de Betão da Indústria de Pré-Fabricação com Agregados Reciclados”, Relatório ICIST, DTC 47/13, Lisboa, Novembro de 2013.

Soares, D.; Pacheco, J.; Brito, J. de; Ferreira, J.: "Estado da Arte: Betões com Incorporação de Agregados Grossos Reciclados”, Tarefa 1 do Projecto “Utilização de Resíduos de Betão da Indústria de Pré-Fabricação com Agregados Reciclados”, Relatório ICIST, DTC 47/13, Lisboa, Novembro de 2013. s”, Relatório ICIST, DTC 46/13, Lisboa, Novembro de 2013.

Soares, D.; Pacheco, J.; Brito, J. de; Ferreira, J.: "Planeamento dos Ensaio dos Agregados e Betões”, Tarefa 1.2-A do Projecto “Utilização de Resíduos de Betão da Indústria de Pré-Fabricação com Agregados

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# Use of non destructive testing to assess the diameter and integrity of jet grouting columns complemented with laboratory tests

**KEY WORDS:** jet grouting; geometry prediction, soil-cement mixture; geophysical tests

**PROMOTING INSTITUTION(S):** IST-ICIST

**PARTNER INSTITUTION(S):** LNEC and OPWAY

**PERIOD:** 2012 to 2014

**FINANCING (€):**94,810€

**IST/ICIST:** 10,025€

**COORDINATOR(S):** Rafaela Cardoso (ICIST-IST)

**RESEARCHERS AND COLLABORATORS:** Daniel da Costa Ribeiro, Raquel Néri

## SUMMARY

Jet grouting is a technique used to treat soils to improve their stiffness and strength and to make them adequate as foundation materials. The technique is relatively simple and can be economically advantageous when compared with more traditional solutions, in particular because *in situ* soil is used instead of being excavated and placed elsewhere. However, it has some limitations, being the most relevant the uncertainty of the final shape of the injected column, the hydro-mechanical properties of the soil-cement mixture and its homogeneity in depth.

Visual inspection and sampling for laboratory tests of some columns excavated after their construction is mandatory in order to verify if the injection technique and quantity of cement used are appropriated. The main objective of this research is to test and improve the ability of geophysical tests to predict the diameter of columns made of jet grouting. Adding to this, The characterization of the hydro-mechanical properties of soil-cement mixtures for different compositions and water/cement relationship will also be studied through experimental tests.



Solo                      150kg/m<sup>3</sup>                      200kg/m<sup>3</sup>                      250kg/m<sup>3</sup>                      350kg/m<sup>3</sup>                      Calda  
A/C=2,0 A/C=0,6                      A/C=1,7 A/C=0,6                      A/C=1,3 A/C=0,6                      A/C=1,0 A/C=0,6                      A/C=0,6

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