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Instituto de Engenharia de Estruturas, Território e Construção

Concluded

PhD Theses

2012 to September 2014

Draft

INDEX

One-Dimensional Models for the Spatial Behaviour of Thin-Walled Bars with Open Cross-Sections: Static and Dynamic Analyses

Anísio Andrade

ABSTRACT

Tapered thin-walled bars are extensively used in the fields of civil, mechanical and aeronautical engineering. The competitiveness of tapered structural members is hindered by the fact that their spatial behaviour is still poorly understood and by the lack of rational and efficient methods for their analysis and design. The present thesis aims at providing a contribution to overcome these drawbacks, by (i) developing one-dimensional models (*i.e.*, models having a single independent spatial variable) to perform linear static, dynamic and lateral-torsional buckling analyses of tapered thin-walled bars with open cross-sections, (ii) supplying physical interpretations for the key behavioural features implied by these models and (iii) offering a detailed examination of several illustrative examples that will be useful for benchmarking purposes.

The first part of the thesis is devoted to bars whose shape allows them to resist biaxial bending by the membrane action of their walls. It starts with the development, based on the induced-constraint approach, of a linear one-dimensional model for the stretching, bending and twisting of tapered thin-walled bars with arbitrary open cross-sections under general static loading conditions.

For a large class of tapered thin-walled bars with open cross-sections, the membrane strain and force fields implied by the internal constraints do not have the same form as in Vlasov's prismatic bar theory – they feature an extra term, involving the rate of twist. Consequently, the torsional behaviour (be it uncoupled or coupled with other modes of deformation) predicted by our tapered model is generally at odds with that obtained using a piecewise prismatic (stepped) approach. The discrepancies may be significant, as illustrated through examples. The developed linear model is then extended into the dynamic range. The contributions of rotatory inertia and torsion-warping inertia are fully taken into account. The inclusion of a viscous-type dissipative mechanism is briefly addressed.

The second part of the thesis is concerned with strip members exhibiting constant thickness and varying depth. It deals with three problems of increasing complexity: (i) the elastic lateral-torsional buckling of cantilevered beams with linearly varying depth, acted at the free-end section by a conservative point load; (ii)the elastic lateral-torsional buckling of cantilevers; (iii) the elastic flexural-torsional buckling of linearly tapered cantilever beam-columns, acted by axial and transverse point loads applied at the free-end section.

These three problems are tackled analytically – we obtain exact closed-form solutions to the governing differential equations and, thereby, establish exact closed-form characteristic equations for the buckling loads. However, in the third problem, the analytical approach is successful only for certain values of the ratio between the minimal and maximal depth of the strip beam-column – in the remaining cases, it is necessary to resort to a numerical procedure.

Theoretical and experimental study on the behavior of typical floors heritage buildings. Restoration solutions.
Daniel Pericleanu

SUPERVISORS: Ana Maria Gramescu (Ovidius University of Constanta, Faculty of Civil Engineering), João Gomes Ferreira (Instituto Superior Técnico)

KEY WORDS: Vaulted Floors, Restoration, Heritage

INTRODUCTION:

Heritage buildings are facing anthropic and natural deterioration. Knowledge of the effects of these destructive factors together with a thorough knowledge of the construction monuments in detail are essential in enabling technicians to select appropriate restoration methods and techniques to protect historical components valuable substance and cultural value.

The analysis performed on heritage buildings focused on vaulted floors, namely on their characteristics, their behavior and their response to intervention measures. Over time these elements have undergone a progressive evolution from the materials point of view, technologies and constructive solutions (using planar components, the vaults, the arches and other forms of curvature).

The behavior in time of these elements was analyzed as well as the structural parameters that influence the structural conformation, factors defining vulnerability and techniques to improve the mechanical behavior of vaulted floors, necessary within the action of restoration and conservation of heritage buildings.

Within the activities performed, a significant number of heritage buildings was studied, including the materials used, both homogeneous structure and the composite structure, as well as used technologies, so that the new restoration solutions proposed can be founded on the authentic elements of the monument.

Studies and investigations done during research aimed ultimately at characterizing methods and intervention techniques appropriate to be used in different structural compositions of floor in order to improve its mechanical behavior.
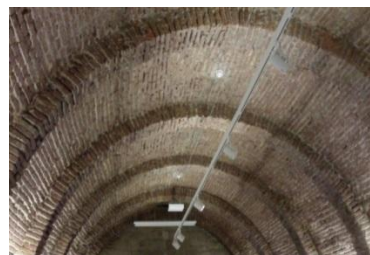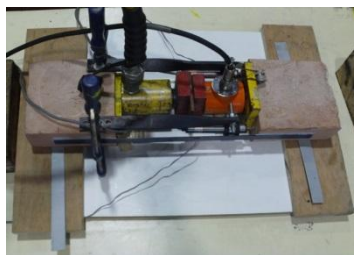
Adherence test between CFRP laminate and old brick of a vaulted floor

Applications of Spatial Analysis Techniques in the Conservation of Paintings
Frederico José Rodrigues Henriques

SUPERVISORS: Ana Calvo (Escola das Artes, Univ. Católica Portuguesa), Alexandre B. Gonçalves (IST/ICIST)

KEY WORDS: Documentation, Technical Analysis, Photogrammetry, Geographic Information Systems, Landscape Metrics, Photo Interpretation

INTRODUCTION: In the framework of Geospatial Technologies (GT), the study of the terrestrial surface through various processes of acquisition, processing and analysis of spatial information, related to the most varied phenomena, is often done. However, the abstraction of models and methods used for this purpose allows their application in the spatial analysis of any other surfaces, such as the digital images of paintings. This extension of the traditional field of GT allows quantifying multiple spatial characteristics of the surfaces interesting in the documentation for Heritage Studies. Despite the clearly different scales between the two domains of knowledge, the representation and analysis of paintings can be performed with methodologies generally used to characterise the terrestrial surface, being useful in the documentation process for Conservation, especially in the visualisation and in the pictorial spatial quantification. The thesis presents some perspectives on the application of Geographic Information Systems (GIS) in the spatial analysis of paintings, aiming to document surface phenomena, as well as the results of processes of classification and image analysis with landscape metrics.

EXPERIMENTAL RESULTS: Description, application and result interpretation for several case-studies using geospatial technologies and GIS functions in selected artworks, including photogrammetry and orthophotography, image classification for the evaluation of geometric properties of the pictorial surface (mainly for the extraction of pathological origin features) and landscape metrics.

Figure 1. Result of a Maximum Likelihood Classification for the lacunae in a wall painting.

Figure 2. Orthophotograph of a panel painting and the corresponding thematic map of lacunae, retouching areas and main colours.

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Seismic Vulnerability of Pombalino Buildings

Helena Alves Meireles

SUPERVISORS: Rita Bento (IST); Andreas Kappos , Aristotle University of Thessaloniki, Greece

KEY WORDS: Pombalino buildings, H/V spectral ratio technique, cyclic static shear testing with imposed displacements, hysteresis curve, macro-element modelling, fragility analyses.

INTRODUTION: The heritage value of the mixed wood-masonry 18th century Pombalino buildings of downtown Lisbon is recognized both nationally and internationally. The present thesis focuses, first, on the definition of the soil characteristics of Lisbon downtown and on the definition of the seismic action for assessment. The site selected (Lisbon downtown) is set on an alluvium filled valley of soft unconsolidated sediments where considerable seismic site amplification of ground motion is expected. Albeit the importance and susceptibility of the site, not much information is available in the literature for seismic ground characterization. So, a collection of data has been gathered from various sources, mostly from geological and geotechnical surveys. Additional measurements of ambient vibrations have been performed based on the H/V spectral ratio technique (HVSRT). Based on the combination of geological and geotechnical data with HVSRT, it was possible to characterize the alluvium site in terms of average shear wave velocity of the soil (Vs,av) and depth to bedrock estimates, as well as mapping the site quarters where seismic ground amplifications are expected. The site Vs,av of the soil is estimated at ~194 m/s. Second, a focus was given on the interior walls of the Pombalino buildings called "frontal" walls. An experimental campaign to obtain the hysteretic behaviour of these "frontal" walls was carried out by static cyclic shear testing with imposed displacements. A total series of three tests were conducted in three identical real size walls. The hysteretic behaviour of such walls subjected to cyclic loading exhibit high nonlinear force-displacement responses and high ductility. As previous experimental studies on "frontal" walls are very limited, these results are an important contribution to the state of the art. Third, based on the experimental results obtained, a macro-element was proposed for "frontal" walls. This was obtained based on the development of a hysteretic model to describe the cyclic behaviour of the Pombalino "frontal" walls. The hysteretic model, based on phenomenological approach, aims to reproduce the response of a wall under general monotonic, cyclic or earthquake loading and is related to a minimum number of path following rules. The model was constructed using a series of exponential and linear functions. There are a total of nine identifiable parameters in this model to capture the nonlinear hysteretic response of the wall. These were all calibrated with experimental data. Finally, the last part of this study focuses on the modelling of a typical Pombalino building with a structural software called 3Muri (www.stadata.com) where the previously described macro-element for "frontal" walls has been incorporated. The modelling includes macro-elements for the masonry panels and, as a new accomplishment for the state of the art, macro-elements also for the internal "frontal" walls. Pushover analyses were carried out and the seismic assessment of the building was evaluated. Further ahead, fragility curves and damage probability plots were obtained. The most important application of such curves is in loss estimation studies and this is further ahead proposed work. Last, some retrofitting strategies were modelled also in 3Muri program and the seismic assessment and fragility analysis were carried out also for these situations.

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Time-dependent Behavior Of RC Elements Strengthened With LWAC

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SUPERVISORS Eduardo S Júlio (IST - ICIST)

KEY WORDS: LWAC, strength, density, Young's modulus, shrinkage, creep, interface strength

INTRODUCTION: Nowadays, the production of lightweight aggregate concrete LWAC, simultaneously with high strength and reduced density, has an increasing interest. Aiming to develop a mixture design method for LWAC, using lightweight expanded clay aggregates, an experimental research study has been conducted. The mechanical properties, the time-dependent properties and the strength of the interface between LWAC and a concrete substrate have been assessed. The developed method can be used, reliable and accurately, to design not only LWAC but also LWAC with special requirements. Corrections are proposed to codes predictions, mainly for Young's modulus, shrinkage and creep. Important LWAC parameters have also been studied to better predict the interface strength of composite concrete elements using this material.

MAIN OBJECTIVES: (i) to develop a mixture design method for LWAC and adapt it to LWAC with special requirements; (ii) to characterize the mechanical properties of LWAC; (iii) to characterize the time-dependent properties of LWAC; (iv) to study the parameters and characterize the interface strength of composite elements with LWAC; (v) to develop a parametric study to correct the codes predictions which are not correctly considered.

EXPERIMENTAL RESULTS:
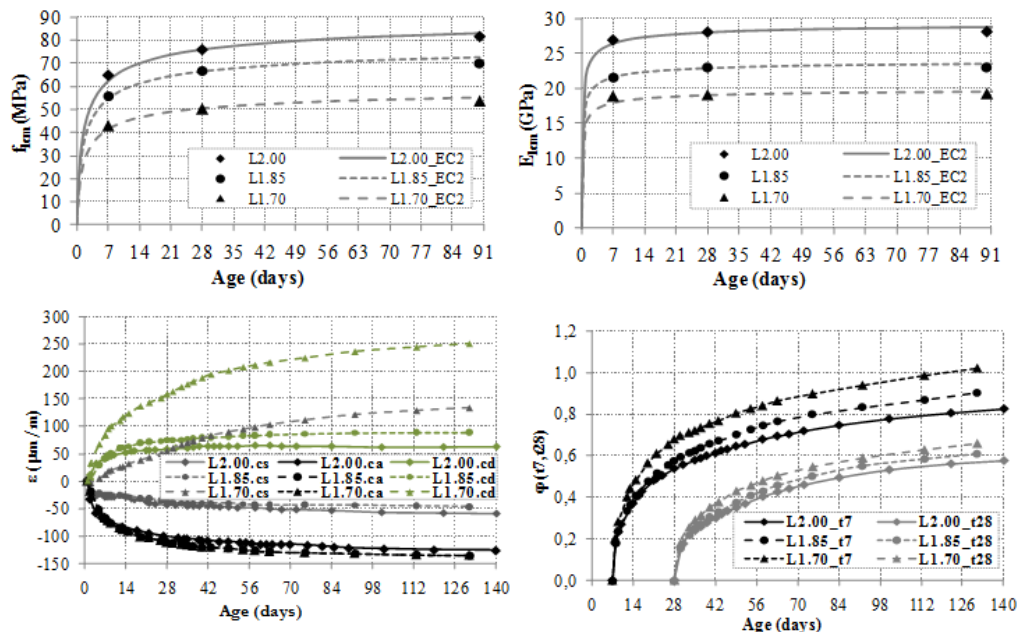
CONTACTS: hcostah@gmail.com; hcosta@isec.pt; phone: (+351)960071786 (2013)

Self-hardening Slurry Walls. A Contribution for Design, Quality Control and Performance Monitoring

Joana Maria Rodrigues Carreto

INTRODUCTION:

Self-hardening slurry wall technology has great potential for application in Portugal both in the rehabilitation of dams as in the containment of contaminants. However, contrary to the trend observed in other countries, its application, at this date, is limited to 6 works. The lack of experience and the unique behaviour of self-hardening slurries, which has no parallel with the well-known behaviour of soils, cemented soils and concrete, may explain the reason why this technology has seldom been applied in Portugal.

An extensive laboratory testing programme was conducted to characterize the physical, mechanical and hydraulic behaviour of the slurry both in liquid as in solid state and to give a realistic insight of the material *in situ*. Particular attention was given to the impact of the slurry microstructure in its macroscopic properties.

The most innovative character of this work consists in the integrated analysis of the phenomena associated with the construction of the wall – spoil contamination, sedimentation, penetration of slurry, filtration, consolidation and cement hydration and pozzolanic reactions. An attempt is made to quantify the effects of these phenomena and to include these effects in the design of the wall.

Fundamentally, a contribution is given for the development of rational design standards, for the definition of rules for quality control during construction and for the definition of performance monitoring procedures, and thus towards the designing of more cost-effective structures.
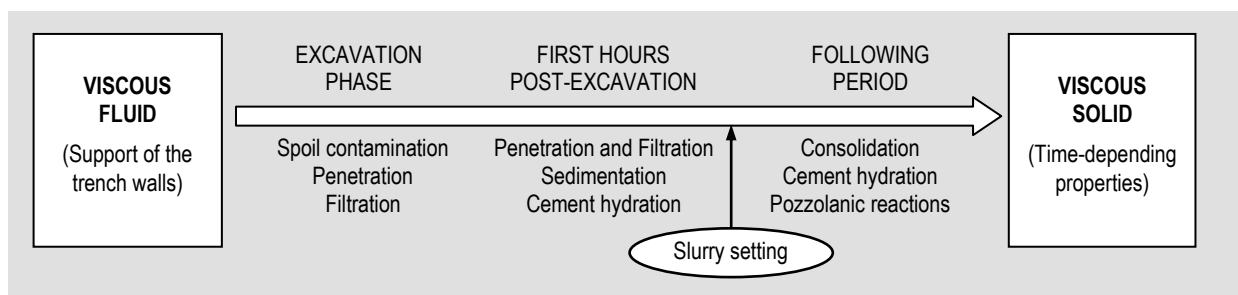
Processes involved in the formation of the slurry wall material.

Connection Capacity Between Micropile and Existing RC Footings

João Paulo Veludo Vieira Pereira

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SUPERVISORS: Eduardo S Júlio (IST - ICIST); Paulo L Pinto (UC)

KEY WORDS: bond, strength, confinement, retrofitting, interface, micropile, grout, push-out tests, pull-out tests

INTRODUCTION: Strengthening foundations with micropiles is progressively being used, due to the major advantages that this technique presents. Nevertheless, the influence of some relevant parameters in the overall behavior of the retrofitted foundations has not yet been studied. Generally, micropiles are installed in holes drilled through the existing RC footing, which are then filled with grout. The efficiency of the load transfer mechanism depends on the bond strength of both the micropile-grout and the concrete-grout interfaces. An experimental investigation was performed to specifically study the influence of some parameters on the bond strength between micropile-grout-concrete interface.

MAIN OBJECTIVES: The load transfer mechanism depends on the behaviour of the micropile/grout/concrete interface. Thus, this study aims to contribute to the knowledge of the behaviour of these interfaces, being addressed the effect of: (i) textured of the hole surface; (ii) texture of the micropile; (iii) hole diameter; (iv) micropile embedment length; and (v) level of confinement of the RC footing. Design and detailing guidelines are proposed.

EXPERIMENTAL RESULTS: For smooth micropile inserts bond strength was found to increase with the decrease of the hole diameter and with the increase of the confinement level of the RC footing. For textured micropile inserts the capacity of the micropile-to-footing connection increases with the increase of the insert embedment length and with the decrease of the hole diameter. In addition, it was concluded that an adequate active confinement must be provided to achieve the required capacity

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Structural Health Monitoring of Concrete Structures Using Image Processing and Multi-spectral Analysis

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SUPERVISORS: Eduardo S Júlio (IST - ICIST); Helder J Araújo (FCTUC)

KEY WORDS: Concrete pathology, structural health monitoring, photogrammetry, digital image processing, multi-spectral Analysis

INTRODUCTION: A new method named 'Automatic Concrete Health Monitoring' (ACHM) was developed to monitor the behaviour of concrete structures/members subjected to load and to detect and characterize surface damages in exposed concrete structures. The method uses photogrammetry, digital image processing and multi-spectral image analysis, considering both visible and near infrared spectrum, to evaluate concrete pathology. ACHM proved to be able to automatically characterize and monitor different concrete anomalies.

MAIN OBJECTIVES: (1) To automatically monitor, during laboratorial tests, parameters such as displacement field, strain field and crack pattern; (2) To automatically identify and map anomalies in concrete surfaces, such as cracks, moisture, stains, biological colonization and repair materials.

EXPERIMENTAL RESULTS: Displacement field, strain field and crack pattern
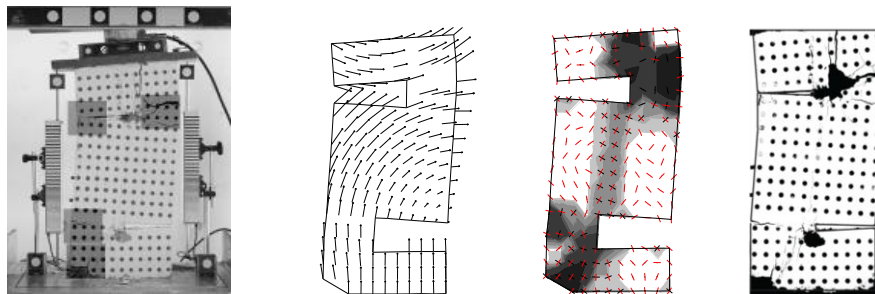
Concrete Damage Maps
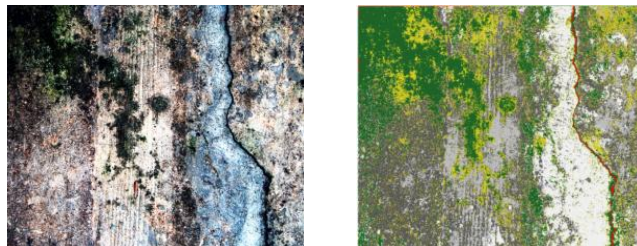
CONTACTS: Email: jonatas@isec.pt; telm:91 882 3733 (2012)

LIFE CYCLE STUDY OF ROADWAY BRIDGES Support system for comparative analysis of life cycle costs of diferente solutions for concrete roadway bridges
José Carlos Costa de Almeida

SUPERVISORS: Paulo Cruz 1 (ISISE, Universidade do Minho, Guimarães, Portugal), Jorge de Brito (ICIST, DECivil, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal)

INTRODUCTION:

Throughout the years the road network has evolved alongside society. Nowadays, as well as throughout the ages, it has played an important role in both social and economical development. Due to their unique features, bridges are structures that allow roadways to cross over rivers, canals, roads, valleys and many other natural or manmade obstacles. Given that the deterioration of bridges is inevitable, it is crucial that their management is accomplished by optimizing the increasingly scarce economic resources.

The aim of this Thesis is to create an innovative method that quantifies the life cycle costs of concrete decks of roadway bridges that supports the decision-making regarding the optimal selection between several construction / repair alternatives.

The Thesis starts with a presentation of existing bridge management systems, at a worldwide and national level, with the purpose of demonstrating the need for a fast and intuitive system for supporting the decision-making process.

The main deterioration mechanisms of concrete decks are presented along with some deterioration models based on the main material and environmental characteristics of bridges.

Some of the most modern materials that are used on concrete bridges are also presented and characterized. These materials are briefly described and their main properties are summarized with a special focus on their cost and service life. Some advantages and disadvantages of their applications are also presented.

After the determination and presentation of the direct costs, the quantification of the user costs is presented. These calculations are made taking into account the vehicle operating costs, the cost of time and accident costs. The user costs are determined by comparing the traffic costs under free flow conditions with those that result from conditioning the traffic flow.

The model created is applied to an existing bridge, where the determination and comparison of the costs of the application of different repair alternatives are analysed. In order to be able to make some recommendations of operation sensitivity analysis of the parameters that are considered most important is performed.

The main conclusions and recommendations are presented at the end of the Thesis, and some suggestions are made for future development resulting from limitations of the model created.

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Life cycle assessment "from cradle to cradle" of building assemblies - Application to external walls
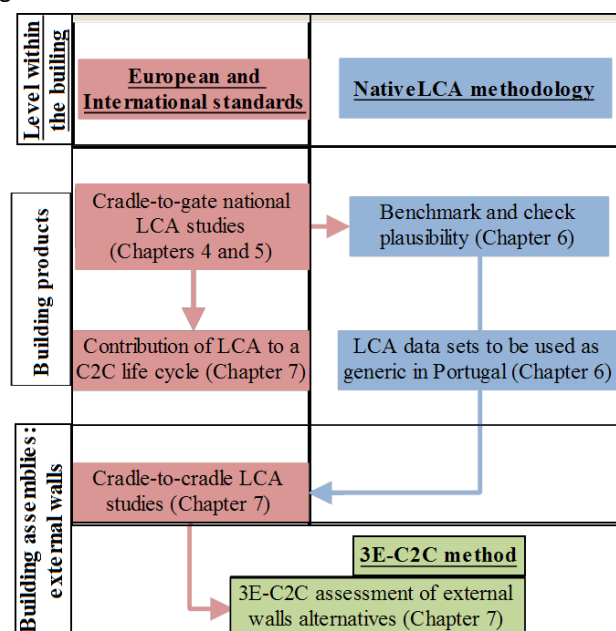José Dinis Silvestre

SUPERVISORS: Doctor Jorge Manuel Caliço Lopes de Brito (Instituto Superior Técnico, Universidade de Lisboa), Doctor Manuel Guilherme Caras Altas Duarte Pinheiro (Instituto Superior Técnico, Universidade Técnica de Lisboa)

INTRODUCTION: This PhD thesis on Civil Engineering was presented at Instituto Superior Técnico (IST), Universidade Técnica de Lisboa.

The aim of this research is to improve the coherence and applicability of the environmental, economic and energy life cycle assessment "from cradle to cradle" of building materials and assemblies. To achieve this goal, Life Cycle Assessment (LCA) studies were completed, and two methodologies intended to be innovative at an international level are proposed. LCA studies of 12 building materials based on production data of Portuguese companies are presented and include innovative products at an international level. A methodology for the selection of a coherent LCA data set to be used as generic for a national context (NativeLCA) was developed. NativeLCA provides data required by European standards, and can also be used to confirm the plausibility of LCA results. Its feasibility was proven in the application to 16 building materials, and potential improvements were identified.

A method (3E-C2C) for the assessment of the environmental, economic and energy performance of building assemblies "from cradle to cradle" using standardized criteria is proposed. 3E-C2C was applied in the design of an external wall for a building in Portugal through the quantification of each dimension of performance using the same unit. This case study tested, validated, and contributed to the improvement of 3E-C2C. Approaches developed in the scope of this PhD Thesis and corresponding deliverables:

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Behavior of concrete made with fine recycled concrete aggregates

Luís Manuel Faria da Rocha Evangelista

INTRODUCTION: The construction industry has an high impact on the environment, not only because of the high amounts of natural non-renewable resources used, but also because of the considerable quantities of construction and demolition waste (CDW) created. One of the key solutions to reduce construction's "ecological footprint" is the recycling of C&DW, especially using them as aggregates for concrete production, replacing their natural counterparts.

Even though the use of coarse recycled aggregates is currently accepted, to some extent, in a great number of countries with practical application on the field, the use of fine recycled aggregates (FRA) is generally forbidden or strongly restrained, limiting the use of an important portion of CDW that can be as high as 50% of the total CDW generated. These restrictions are mainly due to the properties of FRA which have high water absorption and high quantities of contaminants. In spite of that, some recent studies have pointed out that FRA, especially those from concrete, can be a valuable source of aggregates for concrete production.

Considering this, this thesis aims at researching as extensively as possible the mechanical, rheological and durability performance of concrete made with fine recycled aggregates (CFRA), comparing the results with those observed in reference concrete, made with natural aggregates only, with similar compositions. Finally, reinforced concrete beams made with CFRA were tested and analysed both in terms of relative and absolute behaviour, taking into account the current standards.

The results achieved show that mechanical performance of CFRA is slightly affected by the use of FRA, while both durability and rheology performances suffer greater loss. Generally speaking, this work shows that it is possible to use FRA in concrete production, as long as the FRA's properties and specificities are considered both in concrete's mix design and production.

Behaviour and Load Carrying Capacity of Stainless Steel Structural Members
## Miguel da Silva Abambres

SUPERVISORS: Nuno Silvestre (IST - ICIST), Dinar Camotim (IST - ICIST)

KEY WORDS: Stainless Steel, Cold-Formed, Structural Behaviour, Generalized Beam Theory (GBT), Elastic-Plastic Analysis, Post-Buckling Analysis.

INTRODUCTION: This work aims to propose new computational tools to accurately analyze the structural behaviour and predict the ultimate resistance of cold-formed stainless steel elements. In particular, original formulations of the Generalised Beam theory (GBT) will be developed, computationally implemented and validated in order to perform physically non-linear first order and post-buckling analysis of thin-walled members made of arbitrary non-linear materials with isotropic/anisotropic hardening. These innovative GBT formulations account for the effects of geometric imperfections and residual stresses, and the results obtained will be validated against the ones provided by shell finite element analysis performed in software ABAQUS. Lastly, and in order to assess the accuracy of the aforementioned numerical models, an experimental program is followed to test cold-formed stainless steel columns, beams and beam-columns.

MAIN OBJECTIVES: The main goal is to develop powerful, versatile and efficient computational tools based on the Generalized Beam Theory (GBT) to accurately analyze the structural behaviour and predict the load bearing capacity of cold-formed stainless steel elements.

EXPERIMENTAL RESULTS: In order to assess the accuracy of GBT-based and ABAQUS-based numerical models in predicting the structural behaviour of cold-formed stainless steel members, an experimental program is performed, comprising tests on columns and beams
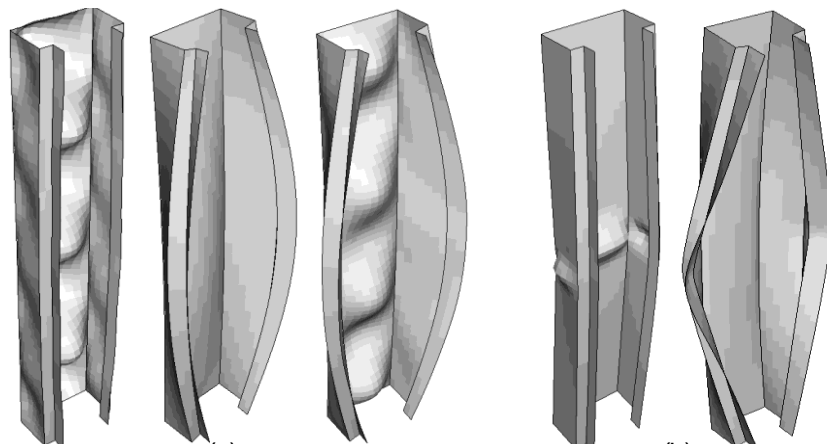
CONTACTS: abambres@civil.ist.utl.pt; nunos@civil.ist.utl.pt; dcamotim@civil.ist.utl.pt (2014)

Contributions regarding the techniques and methods of conservation and restoration of natural stone buildings

Mihaela Drăgoi

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KEY WORDS: Conservation, Built Heritage, Natural Stone, Consolidation Treatments, Water Repellent Treatments

ABSTRACT:

The PhD thesis gives a contribution to the knowledge about the materials, degradations forms and conservation of the Romania´s masonry and its part in the country´s heritage. The experimental research component is focused on the characterisation of Romanian stone materials, water repellent and consolidation treatments applied on these materials and on methods and tools for diagnosing the action of treatments.

The thesis presents an overview of existing proposed methodologies for studying the action of consolidation and hydrophobic treatment of natural stones and analyses the achieved experimental research results concerning the action of the tested treatments in the scope of those proposals.

The thesis proposed a form with guidelines to support the description, analysis and conservation of the built heritage. The proposed guide sheet could be a useful tool for the inventory and assessing the state of conservation of built heritage.
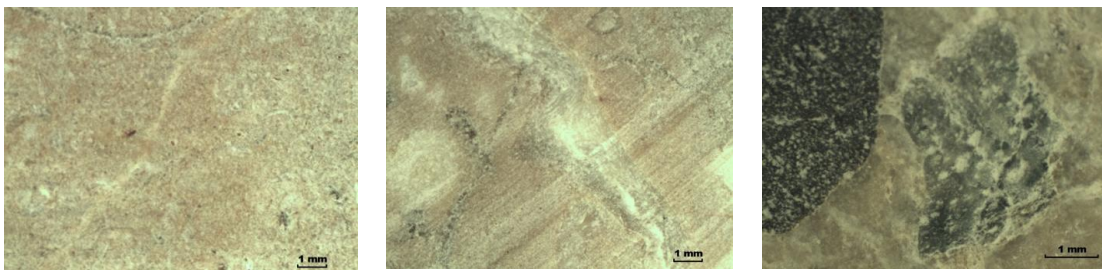
CONTACTS: Ana Paula Ferreira Pinto; anapinto@civil.ist.utl.pt – Concluded 19/06/2014

Behaviour and Strength of Thin-Walled Laminated FRP Composite Structural Elements
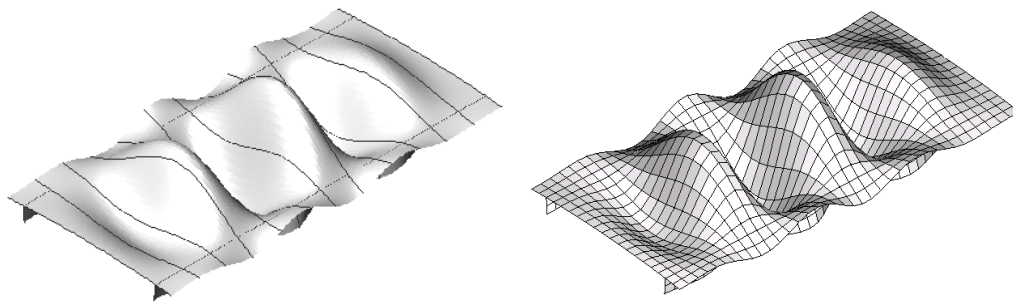## Nuno Silva

ABSTRACT
One presents several original Generalised Beam Theory (GBT) formulations suitable to describe the behaviour and strength of thin-walled prismatic structural elements (i) of arbitrary cross-sections constituted by elastic isotropic or orthotropic (composite) laminated FRP materials and (ii) subjected to general loading cases and support conditions. Arbitrary cross-sections are handled using a new GBT cross-section deformation description that (i) takes into account global, local, shear and transverse extension deformation and (ii) identifies a new set of deformation modes in cross-sections with closed cells, *i.e.*, the *cell shear flow modes*, including the torsion mode. The effects of the (i) load application point with respect to the cross-section shear centre and (ii) transverse normal stresses due to concentrated transversal loads are included in the GBT buckling and post-buckling formulations. The problems of rigorously modelling (i) the composite walls constitutive laws and (ii) boundary conditions in GBT are also tackled. The upgraded versions of the theory are numerical implemented resorting to GBT-based finite elements in order to perform linear, buckling and post-buckling analyses of beams, columns and panels. The GBT results are validated using both shell finite element simulations and experimental data obtained specifically for this work concerning the linear and stability behaviour of Glass Fibre Reinforced Polymer (GFRP) profiles subjected to transverse loads.

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Durability evaluation of self-compacting concrete (SCC)

Pedro Miguel Soares Raposeiro da Silva

SUPERVISORS: Jorge Manuel Caliço Lopes de Brito (IST)

KEY WORDS: Self-compacting concrete; Durability; Mechanical properties; Shrinkage; Microstructure Permeability; Capillarity; Diffusion; Chlorides; Carbonation; Mineral additions; Limestone filler; Fly ash.

INTRODUCTION:

The specific workability needs of the self-compacting concrete (SCC), due to the absence of vibration, imply, among other changes, an increase in volume of the fine material in the mixture (cement and additions).

It is therefore possible to link the need for a higher volume of fine material in SCC with the urgency to reduce the global consumption of cement, due to the high CO_2 emissions associated with its production, which, in the short term, may be achieved by replacing the clinker and/or the cement itself by other materials such as, limestone filler (LF) and fly ashes (FA). It is nevertheless essential to demonstrate its applicability in larger quantities (both in binary as in ternary mixtures), namely in terms of durability.

therefore, the main objective of this work is to evaluate the properties in the hardened state, with special emphasis to durability, of SCC produced in binary and ternary mixtures of LF and FA, with percentages of cement substitution of 0, 30, 60 and 70%, and with two distinct values of the ratio between total mortar quantity and quantity of coarse aggregate in the mixture.

For this purpose, an extensive experimental campaign took place, to evaluate the properties of the SCC produced, both in the fresh (self-compactability) and in the hardened (mechanical behaviour and durability) state.

In terms of global performance of the mixes studied, it was possible to confirm the viability of producing SCC in binary and ternary mixtures of LF and FA with high ratios of cement substitution.

CONTACTS: Pedro Raposeiro da Silva; pedro.raposeiro.silva@ist.utl.pt – Concluded 18/06/2013

Modelling of Cement Hydration in Concrete Structures with Hybrid Finite Elements
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SUPERVISORS: J.A. Teixeira de Freitas (ISTUL), R. Faria 2 (FEUP)

INTRODUCTION: The main objective of this work is to develop a hybrid finite element formulation to model cement hydration in concrete structures.

A hybrid formulation of the finite element method is first developed for the solution of heat transfer problems. It is based on the independent approximation of the temperature and heat flux fields in the domain and on the boundary of the element, respectively. The formulation is assessed in terms of convergence and robustness and validated using linear and nonlinear steady-state and transient test problems.

The hybrid model is then used to simulate the thermo-chemical response of ordinary Portland cement concrete using the hydration degree concept. The hybrid formulation is extended to include the simulation of the effect of the heat source and to approximate directly the hydration degree field.

The third development consists in extending the hybrid model to simulate the coupled processes of heat transfer and moisture transport in concrete. Two fields are approximated in the domain of the element (temperature and relative humidity) and on its boundary (heat and moisture fluxes). The model can be used to simulate the hygro-thermo-chemical response of both hardening and hardened concrete and is valid for ordinary Portland cement and high-performance concrete. Therefore, and besides the hydration reaction, the supporting mathematical model is extended to simulate the effects of the silica fume reaction and silicate polymerization in heat generation and in moisture consumption. The corresponding degrees of reactions are also approximated in the hybrid finite element model.

Particular attention is paid to the simulation of the boundary conditions that occur in practical applications, which are typically nonlinear and vary in time and in space. This is essential to assess the performance of the formulation using the laboratory experiments and the in situ tests reported in the literature. These tests include one- and two-dimensional problems, as well as axisymmetric and three-dimensional applications.

Particular attention is also paid in what concerns preserving the computational advantages offered by hybrid finite element formulations. The approximation bases are orthogonal and naturally hierarchical to induce high sparsity indices and enable adaptive p-refinement. The solving system is not condensed at element level to enhance parallel processing. The approximations of the state variables and of the geometry are uncoupled to enable the use of unstructured, coarse meshes of high-degree elements. The approximation of the state variables is also uncoupled directionally in space to implement elements with high aspect ratios frequently needed in the simulation of staged construction of concrete structures.

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The Development of Non-iterative Numerical Methods Applied to The Nonlinear Analysis of Structures
Rui Carlos Gonçalves Graça e Costa

SUPERVISORS Jorge Alfaiate (IST - ICIST), Daniel Dias-da-Costa

KEY WORDS: Nonlinear structural modelling, Non-iterative methods, Nonlinear fracture mechanics, Non-proportional loading, Mixed-mode fracture.

INTRODUCTION: In this thesis, new non-iterative procedures are presented for the numerical analysis of concrete and masonry. Numerical examples are used to illustrate the capabilities of the proposed procedures, namely, their use on structures under proportional and non-proportional loading. A solution control energy based criterion is applied in order to capture critical bifurcation points. It is shown that this new methodology is suitable for the modelling of nonlinear structural behaviour in which localization of initially severe distributed cracking is hard to capture with conventional iterative methods. Furthermore, a new mixed-mode fracture model is introduced, which is particularly adapted to the non-iterative procedures developed.

MAIN OBJECTIVES:
New non-iterative methods to solve nonlinear structural behaviour; new mixed-mode fracture model.

EXPERIMENTAL RESULTS:
The work presented in this thesis is numerical; experimental results are only used to validate the numerical results.
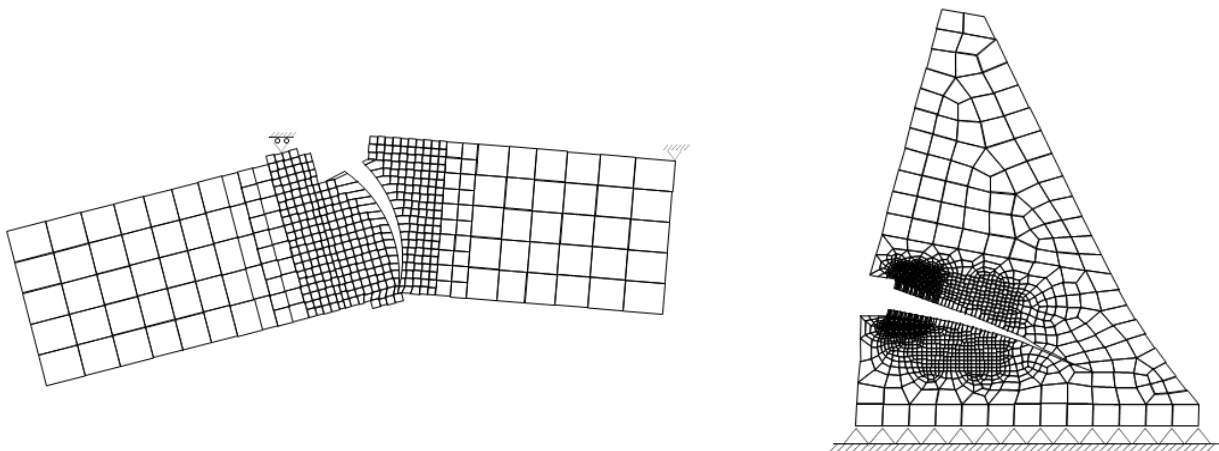
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Air permeability of concrete and carbonation in structures
Rui Duarte Neves

INTRODUCTION: The work aims to contribute to improve the knowledge in the prediction of service life using performance requirements and in monitoring site compliance with these requirements. Two properties that can be used as performance requirements: carbonation resistance and air permeability, are analyzed.

Within the scope of resistance to carbonation, the spatial distribution of carbonation depth in structures is characterized and the adequacy of the classical model to simulate the evolution of carbonation depth in natural and in accelerated conditions is evaluated.

The relationship between resistance to carbonation in natural conditions and resistance to carbonation in accelerated conditions is investigated and a comparison between carbonation depths estimated by the model of the specification LNEC E 465 and those assessed in structures, with long exposure under natural conditions, is performed.

With respect to air permeability, assessments according to Torrent's method are carried out in specimens and structures. The relationship between air permeability and resistance to carbonation is analyzed.

Based on the information obtained in the literature review and on the analysis of experimental results, some recommendations in order to improve the approach to service life design of structures are formulated, particularly with regard to reinforcement corrosion induced by carbonation.

A transformation grammar-based methodology for housing rehabilitation: meeting contemporary functional and ICT requirements
Sara Eloy Cruz

SUPERVISORS: José Pinto Duarte (FAUTL - ICIST), Isabel Plácido (LNEC), Renato Nunes (IST)

INTRODUCTION: This research starts from the premise that the future of the real estate market in Portugal will require the rehabilitation of existing residential areas in order to respond to new life-styles and dwelling requirements that have emerged in an era in which information plays a structuring role in society. The goal of this research is the definition of design guidelines and a rehabilitation methodology to support architects involved in the process of adapting existing dwellings. In addition to defining a general methodology applicable to all the building types, the study focuses on a specific type, called "rabo-de-bacalhau," built in Lisbon between 1945 and 1965 for which a specifc methodology has been generated. Both shape grammar and space syntax were used as part of the rehabilitation methodology as tools to identify and encode the principles and rules behind the adaptation of existing houses to new requirements.

MAIN OBJECTIVES: This research has three main objectives:
Firstly, to identify how the use of technology influences life-styles and creates new dwelling requirements, and how this affects the spatial and functional organisation of dwellings. This work complements Pedro's (2000) and Duarte's (2001) frameworks for incorporating new dwelling modes, new domestic groups, and ICAT-related demands;
Secondly, to define appropriate ICAT sets to incorporate into the spaces in dwellings so as to guarantee environmental sustainability and the social integration of citizens, by adapting them to individual households according to present and future needs. These ICAT sets apply to the dwelling as well as the building, including existing rehabilitated residential stock and new buildings;
Thirdly, to define design guidelines and a methodology to support architects involved in the process of adapting existing dwellings and incorporating ICAT technologies, allowing them to balance new dwelling trends with sustainability requirements.

EXPERIMENTAL RESULTS: The research carried out resulted in a varied set of contributions: i) a characterisation of the "rabo-de-bacalhau" building type; ii) a method for defining the ICAT packs to be integrated into the housing, according to family profiles; iii) the conception of a rehabilitation methodology based on a rigorous process: a general and a specific methodology; iv) the development of a transformation grammar.

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Early design and optimization of the building envelope: Integrating architectural generative design systems and energy performance calculation
Vasco Manuel Ferreira Tameirão Montenegro Granadeiro

SUPERVISORS: José Pinto Duarte (FA-UL), João Ramôa Correia (IST-UL), Vítor Leal (FEUP)

KEY WORDS: Building envelope design, Generative design systems, Shape grammars, Residential buildings, Energy performance, Building energy simulation, Optimization, Genetic algorithms, Representation, Design indicator.

INTRODUCTION: Building design must combine several architectural qualities. Among them is good energy performance. The architectural design variables that most influence the energy performance of a building are the envelope shape, materials, and window areas. As these start to be defined in the early design stages, designers require methods to obtain information about the energy performance of the building. The work presented in this thesis focused on support methods for early design decisions, concerning the design of the building envelope for residential buildings. The work had two driving forces: architectural composition and energy performance. First, a design methodology was devised, proposing a new design process for early stages: the use of architectural generative design systems with integrated energy simulation. After, a representation was created to enable the optimization of the proposed system by genetic algorithms. Lastly, since the use of complex generative design systems is hardly compatible with conventional design processes, a design indicator of energy performance for residential buildings was created. The Frank Lloyd Wright's design system program with integrated energy simulation, developed for this thesis from the grammar for Frank Lloyd Wright's prairie houses and from energy simulation software, was used as a case study throughout the research.
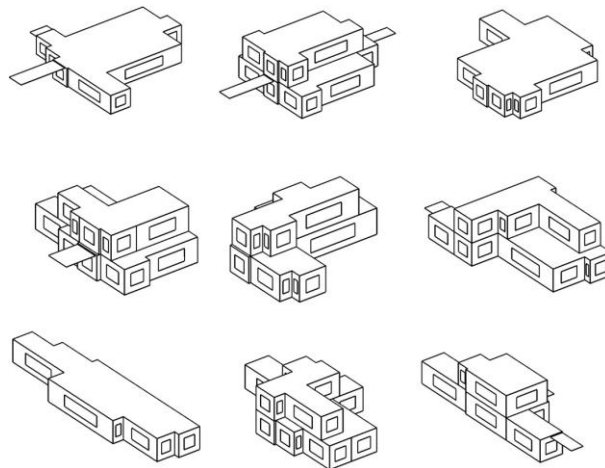
Nine designs, ordered, from left to right and top to bottom, in increasing total annual energy demand per m^2.

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A geometrically exact Kirchhoff–Love shell model: theoretical aspects and a unified approach for interpolative and non-interpolative approximations
Vladimir Ivannikov

SUPERVISORS: Carlos Manuel Tiago Tavares Fernandes (IST/UL), José Paulo Moitinho de Almeida (IST/UL)

KEY WORDS: geometrically exact analysis, nonlinear shell theory, Kirchhoff–Love assumption, essential boundary conditions, hybrid-displacement model, meshless methods, finite elements, MFLS, TUBA, dual analysis

INTRODUCTION: This work proposes a geometrically exact Kirchhoff–Love model, which intends to fill a gap in the approaches currently available for modeling shell structures. Effectively, the shear deformable formulations captured the attention of the majority of researchers and became well studied from both theoretical and numerical points of view. On the contrary, thin shell theories, where out-of-plane distortion is excluded, only recently found practical applicability in nonlinear analysis. Regardless of these advances, the corresponding theoretical background, settled decades ago, has only been partially used due to its intricacy. The basic statements underlying the proposed model aim to simplify the theory and to facilitate its numerical implementation. Typical theoretical issues arising in all thin shell approaches, mainly related to the imposition of the kinematic boundary conditions, are clearly stated. Several possibilities are developed for the consistent and convenient prescription of the boundary rotation. The model naturally captures jumps of torsion moments at singular points of the contour, which compel the imposition of additional pointwise restrains at the corners of the kinematic boundary. The model permits any approximation technique that complies with C^1 continuity requirement to be easily invoked for the numerical implementation. From the group of non-interpolative schemes, the meshless approach was chosen — the Multiple Fixed Least-Squares method and its generalized version were applied. Some properties of the considered element-free technique, crucial for their proper incorporation into the developed shell model, are exposed in the application of dual analysis in linear plane elasticity. Though the construction of C^1 approximation is not straightforward for the finite element method, some possibilities are still available. In the present work, the so-called TUBA family of triangular elements is considered. Initially designed for linear plates, this family was extended to the geometrically nonlinear thin shell problems. A substantial set of popular linear and nonlinear benchmark tests was successfully analyzed. The problems were specially chosen to highlight various aspects — both advantageous and limiting — of the developed shell model.
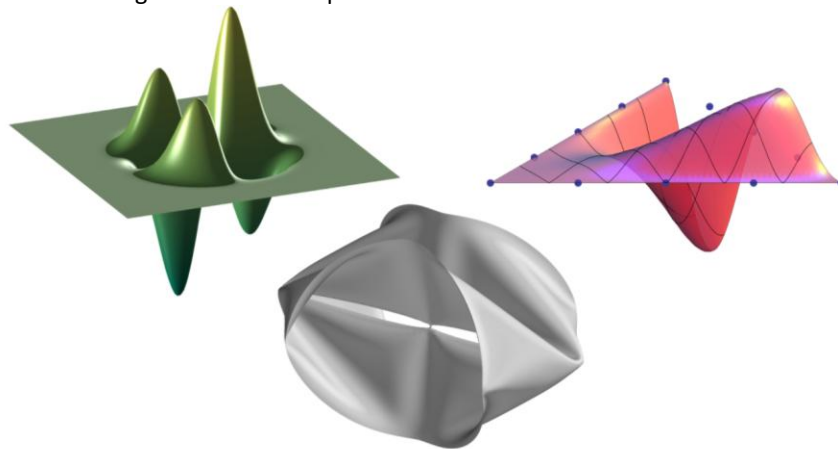
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Risk Management in Construction: Application to urban drainage systems
Vitor Faria e Sousa

INTRODUCTION:
Along with the demographic growth, the evolution of the requirements of the society and the communities, resulted in a substantial increase in the pressure on the natural environment and on the activities. On the one hand, the expectations and requirements imposed on the processes and products have increased significantly in several areas, on the other hand, the available resources are becoming increasingly scarce and limited. Thus, to meet the demands while respecting the constrains, the society must review their models constantly to ensure that it is in the proper path and evolution. In this context, risk management has gained relevance because the individuals in modern and information based societies are becoming increasingly aware and sensitive to the fact that the abundance of information does not provide, necessarily, a greater degree of certainty in decision making.

Fig 1. Quality has a balance between performance and risk.

Being recognized that the construction industry is particularly prone to risks, when compared with the other activities and industries, this doctoral thesis transposes, details and evaluates critically the risk management model of the international standard ISO 31000:2009 for the construction industry and presents a set of approaches for its implementation throughout the life cycle of urban drainage systems projects.

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