Lecture Notes in Networks and Systems 4

Yehia Bahei-El-Din
Maguid Hassan *Editors*

Advanced Technologies for Sustainable Systems

Selected Contributions from the International Conference on Sustainable Vital Technologies in Engineering and Informatics, BUE ACE1 2016, 7–9 November 2016, Cairo, Egypt

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Preface

Modern technologies and techniques in engineering and informatics have been multiplying in the last few decades, affecting the lives of people around the world. Such technologies have come to define modern lifestyles and must face up to the increasing challenges of morphing into sustainable and green technologies. In an effort to catch up with recent technological advances, which are in particular sustainable and have profound effects on people's lives, the British University in Egypt organised its first international conference entitled Sustainable Vital Technologies in Engineering and Informatics in Cairo, Egypt from November 7 to 9, 2016. This book contains papers from the conference, which have been selected to share with the research and professional communities. Focus of the research presented is on advances in (1) Structures, Built and Natural Environment, (2) Energy, (3) Advanced Mechanical Technologies, and (4) Electronics and Communications Technologies. Cultural Heritage, in particular, has several contributions, which focus on preservation, sustainability, adaptation, and rehabilitation. Low carbon/low energy building and/or retrofitting are addressed in a couple of contributions. In advanced mechanical technologies as well as electronic technologies, several papers are contributed with focus on health monitoring techniques and predictive maintenance. Other significant contributions found in this collection include a campus cooling plant, and utilization of nanoparticles to improve the performance of combustion engines.

The time and effort spent by the authors in participating in the conference and preparing the manuscripts for this book are greatly appreciated. The support and funds received from the British University in Egypt for this conference are gratefully acknowledged. Special thanks are due to the Scientific Committee and the Local Organising Committee.

Cairo, Egypt
November 2016

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Part I
Structures, Built and Natural Environment

Demolition of steel structures: structural engineering solutions for a more sustainable construction industry

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Abstract. This paper presents an introduction to structural demolition engineering as applied to steel structures. This work flows out of a research project aimed at providing design techniques for ensuring that structures can be both safely and efficiently demolished when they reach the end of their lifecycles. When a structure is to be demolished or imploded it is typically weakened such that when the collapse is triggered the collapse mechanism can be controlled and will occur as predicted. If structures are not weakened enough they may not collapse when required, but if weakened too much they could collapse prematurely killing demolition teams. This paper specifically discusses (a) a step-by-step analysis of the full-scale demolition of a large structure that the author filmed, explaining the structural mechanics of the system, and then (b) presents methods for weakening structures and how this influences failures. By providing verifiable methods for ensuring structural capacity, rather than relying on experience alone, the demolition process can become more efficient, leading to the increased recyclability of structures and a safer working environment.

Keywords: Demolition; steel structures; safety; structural engineering; weakening techniques; building recyclability.

1 Introduction

The demolition phase of a building is an important stage in its overall lifecycle. To enhance the sustainability of structures it is important the demolition can be carried out efficiently and safely, such that the maximum amount of material can be recycled. At Stellenbosch University various projects and publications have recently been completed on the behavior of steel structures during demolition by van Jaarsveldt, Walls & Dunn (2016; 2016; 2015; 2015), stemming from work started by Jet Demolition. Negligible research exists in the literature regarding structural

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engineering techniques that can be applied when designing buildings for demolition. Guidelines and even codes of practice exist in various countries for guiding the overall process (HK Bldg. Dept. 2004; IS 2002), although these typically note that competent engineers should carry out designs without necessarily providing details regarding how this can be done. In practice most contractors rely on years of experience, which is vital, but experience is seldom complimented by detailed calculation.

The majority of buildings are demolished using mechanical methods, and it is normally the exception to have implosions caused by explosives, although these are typically the type of demolitions covered in the media. Various methods exist for mechanical demolition including: the closed demolition method, cube cut method, reverse construction method, simultaneous dismantling, and the cut and take down demolition method, amongst others (JISF 2015). The author has been involved with projects where large chimneys, power station cooling towers, office blocks and other such structures were demolished. Structural designs for the aforementioned projects were typically developed based on first principle methods, along with significant factors of safety due to the high level of uncertainty regarding structural properties.

2 Case study

The figures below provide an understanding of the demolition process of a structure by considering a case study consisting of a large furnace. This structure was part of a very challenging project where the existing furnace shown had to be demolished within an operational factory, and a new furnace built in the same position, with the whole process needing to happen within around 3 months. Thus, the demolition team had to prepare and bring down the structure very quickly to allow for construction and mechanical teams to access the site. Figure 1 shows a plan layout of the structure. Mechanical demolition techniques were used with the columns and beams being weakened, and the overall process was carried out in three phases. The remaining figures and diagrams relate to the second phase of the process where the middle section of the structure was demolished. Phase 1 had previously been completed in a manner similar to that illustrated below.

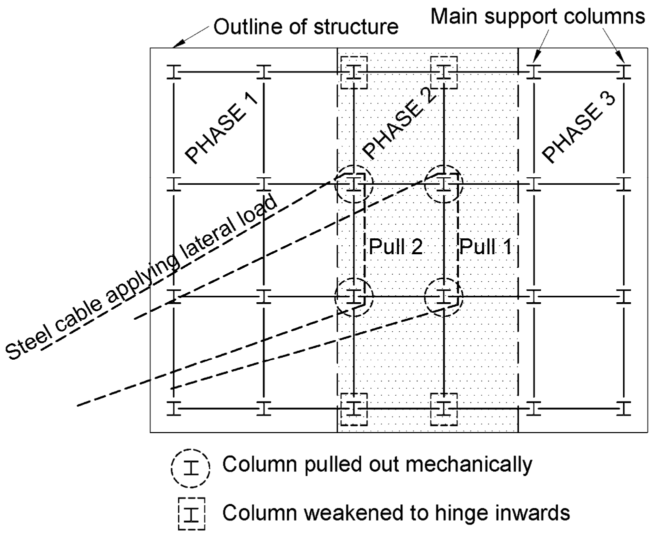

Fig. 1. Layout of furnace to be demolished, showing the phasing of the process

In Figure 2(a) the full structure is shown. The red circles indicate positions where the structure had been weakened. A layer of material around 1m thick had solidified in the furnace, providing a reasonable load on the weakened columns. It must be understood that up until this time teams had been working within this structure, which is potentially very dangerous if structures are weakened more than necessary, or if teams are inexperienced. Techniques for weakening structures typically vary, although in this case cutting torches were used to create holes in sections, or to fully cut members right through. The latter was used for the internal columns that were pulled out. Triangular cuts were used on the outer columns, whilst beams were either fully or partially cut through.

Once the structure was ready to be mechanically imploded a large construction vehicle was used to apply a lateral force to inner columns via a steel cable, as shown in Figure 2(b). The middle columns were prepared such that when this load was applied it caused column sections to fall out. The columns were pulled out by the cable in two steps, with the columns on the right of Figure 1 being removed first, “Pull 1”, followed by the second row of columns, “Pull 2”. The structure was left with sufficient integrity that when the first set of two columns was removed the structure still remained standing. When the second row was removed the collapse was triggered, as shown in Figure 3(a).

Fig. 2. (a) Furnace structure to be demolished. Red circles indicate where structure had been weakened; (b) Lateral load applied to structure to cause internal columns to pull out.

Fig. 3.(a) Structure in the process of collapsing after second line of columns removed;(b) Final pile of rubble which the demolition team could clear and recycle.

It can be observed that as the inner columns move downwards it pulls the upper components of the structure inwards. This ensured that the adjacent structure was protected and all material fell vertically. The resulting pile of rubble is shown in Figure 3(b). At this point in time demolition teams could access the rubble and recycle as much as possible. Once rubble had been cleared the next phase, Phase 3, of the demolition process could commence.

Bracing was left in the structure to provide stability until just prior to collapse when it was cut out. If needed bracing can be left in place to transfer load from one section of a structure to another, ensuring that portions are pulled over at certain times. When overall collapse is considered it is important that once a structure starts collapsing the momentum gained by falling components must be directed in the manner required. Falling material applies loads to any portion of the structure to which it is connected. Also, once columns are removed the load on the adjacent columns is instantaneously increased, so it must be ensured that they have sufficient reserves to carry additional force, or otherwise may inadvertently buckle. Overall it can be seen that the entire process illustrated above occurred quickly, whilst still being safe and allowed the rubble to be easily accessed and removed / recycled.

It was found that during the process one small portion of the structure did fall outwards due to the upper solidified layer providing more stiffness than expected. This slightly damaged an adjacent steel platform, which was quickly repaired. It should be understood that minimal data is typically available regarding structures to be demolished as they are old, have few extant drawings and often have unknown material properties. Hence, designs typically need to be very conservative, and allowance must be made for failures not happening exactly according to plan.

3 Techniques for weakening structures

Now that a basic introduction to the process has been provided it is important to consider how to weaken steelwork to ensure that collapses occur in the direction intended. Figure 4 shows some of the weakened techniques typically used in practice, along with finite element models of the cuts. In relation to the figure presented the following is shown: (a) the double window cut which is used in conjunction with explosives, (b) the triangular window cut which creates a hinge in a controllable manner, and (c) the circular window which provides a reduction in column capacity. Finite element modelling and full-scale tests carried out on such cuts have typically provided good estimates of column capacity prior to the onset of collapse.

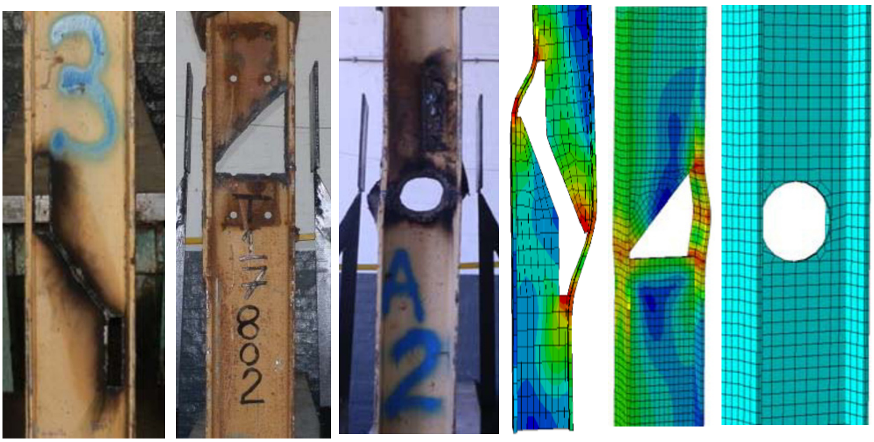

Fig. 4. Selected techniques for weakening columns: (a) double window cut used with explosives; (b) triangular window cut used to cause a hinge; and (c) circular window cut used for general weakening of structures, from van Jaarsveldt & Walls (2016).

It has been found from numerical modelling that the triangular window cut is typically the most predictable of all the cuts, and the flange on the right hand side fails as a mini column. Even though used in practice the circular window cut provides less reduction in capacity than would be expected as the overall buckling resistance of columns is not significantly affected. Often more than one cut is carried out on columns which makes behavior more difficult to predict, especially when slippage between elements occur.

For the internal columns of the furnace that were pulled out sections were cut through fully in the middle, and shims were used to ensure that load was still transferred. The cutting of columns must occur progressively, where after each small section is cut out steel shims are forced into the cut. Since load is still being carried by such columns friction forces exist which ensures that faces of cuts do not slip past each other. If multiple rows must be pulled out by a single cable it must be ensured that paths are created for the cable such that it does not get stuck or apply loads in the incorrect position. In addition to the full-depth horizontal cuts created in the columns that were pulled out additional cuts were created at the top and bottom of columns to create hinges when columns were pulled. The determination of the magnitude of lateral load required to induce collapse is a topic for future research.

4 Conclusions

This paper has provided an overview of the mechanical demolition process by investigating step-by-step the demolition of a furnace. The structure was initially weakened using a cutting torch and then collapse was induced through the application of a lateral load. A thorough understanding of structural mechanics is required to carry out such projects, although structures being demolished can still be unpredictable.

It is important that teams bring down structures in ways that allow the maximum amount of material to be recycled. Furthermore, for the construction industry to be sustainable working practices must be safe. By developing methods for calculating the capacity of structures safety can be more readily ensured.

Acknowledgements

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Preservation of cultural heritage: the design of low-energy archival storage

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Abstract. The preservation of important cultural collections in museums, galleries, libraries etc. provides a legacy for future generations to research and experience their heritage. Guidance and standards for the design of archival storage facilities have typically focused on the provision of a controlled, unfluctuating internal environment. However, the latest revision of PD5454 "Guide for the storage and exhibition of archival materials" published by the British Standards Institution encourages designers to consider passive design approaches to reduce energy consumption. This paper reviews the key elements of the PD5454 document relevant to the environmental design of archives, and temperature stability metrics are proposed for assessing alternative passive design options. Analysis of a case study building designed by Atkins is used to illustrate the application of the proposed metrics. The paper concludes by considering issues to consider for the future development of thermal performance metrics for archives.

Keywords: archive storage; conservation; cultural heritage; BIM; thermal modelling; low-energy design; energy performance

1 Introduction

The preservation of historical and cultural artefacts provides a direct, tangible connection to cultural heritage for future generations. Archival storage facilities are designed for the function of mitigating the physical deterioration of their collections, as well as providing some safeguards to fire, theft and deliberate acts of damage. These collections are mostly irreplaceable, as well as potentially having significant financial value, and their damage or destruction may represent a permanent loss to the appreciation and understanding of our human history.

Until recently the design of mechanical services for archival storage has generally followed a paradigm of "close control" of internal conditions using energy-intensive Heating, Ventilation and Air-Conditioning (HVAC) systems. However, the most recent revision of PD5454 "Guide for the storage and exhibition of archival materials"

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(published in 2012 by the British Standards Institution) permits gradual fluctuation of temperature and relative humidity (RH) within archives where this is considered safe for the collections. This aims to reduce energy use for the conditioning of archives to lessen the impact on the environment as well as cutting down operational costs. Whilst PD5454: 2012 refers to the importance of maintaining stable temperature and RH conditions in archives, it falls short of recommending measurable criteria for assessing design or operational performance. This paper describes a case study of an archive storage facility designed by Atkins and the metrics developed to assess thermal performance at the design stage. These metrics are readily assessed using thermal modelling software and may be used for comparing alternative design options.

2 Design standards for archives

There are a range of published standards and best practice guidance for the operation and management of archives. In a UK context, PD5454: 2012 "Guide for the storage and exhibition of archival materials" is of primary relevance to the environmental design of archival storage facilities. At a European level, conservation standards are currently under development by Technical Committee 346 of the European Committee for Standardization (CEN/TC 346). Standards published under the auspices of CEN/TC 346 that are relevant to defining internal environmental criteria for archives include EN 15757: 2010 "Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials". The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) also define a range of temperature and RH performance target specifications in the ASHRAE Handbook "HVAC Applications".

Environmental risks for the preservation of archive collections cited in PD 5454: 2012 include:

- Mould growth (in damp conditions).
- Potential damage to documents if stored in excessively dry conditions (e.g. when folded, or rolled items).
- Accelerated chemical deterioration if temperatures are excessive.
- Presence of atmospheric pollutants (ozone and sulphur and nitrogen oxides).
- Off-gassing from construction materials or items stored in the archive (e.g. plastics).

Other relevant considerations for the design of archives referenced in PD5454: 2012 include:

- Thermally massive, air-tight construction is recommended to provide stability of environmental conditions. This is also beneficial in the event of HVAC control systems being interrupted by equipment failure or maintenance activities.

- To prevent uncontrolled air changes and potential ingress of pollutants contained in atmospheric air, a new repository "should be built to an air infiltration rate not exceeding two air changes per day".

In relation to temperature and RH conditions, PD 5454: 2012 states that gradual change within recommended control bands may be considered acceptable where this occurs over a period of a month or more. However, it also cautions that "a continuous weekly cycle up and down the ranges will cause a gradually increased rate of deterioration of most archival materials when compared with this rate of change in a very stable environment". Whilst stability in average annual conditions is preferable with respect to preservation, PD5454: 2012 acknowledges the importance of striking a balance with energy economy.

3 Case Study

3.1 *Introduction*

The Atkins design for Plymouth History Centre includes a number of archival storage areas. The largest of these is located on the second floor of the building, cantilevering above a new exhibition space. The design internal environmental criteria for the second floor archive are based on the ranges of temperature and RH defined for "mixed archives" in PD 5454: 2012, which recommends temperatures of 13°C to 20°C and RH of 35% to 60%. A comparison of these design conditions and monthly average weather data for Plymouth is given in Figure 1. Weather data for Plymouth has been sourced from the CIBSE Test Reference Year (TRY) weather file, which is derived from historic observations and is based on the most average weather data for that period i.e. it represents typical weather conditions.

The climate of Plymouth is strongly influenced by its proximity to the sea. This results in higher winter temperatures and lower summer temperatures relative to areas further inland. Figure 1 indicates that average external temperatures fall below the lower temperature band for the winter period (October to April) and therefore heating is likely to be required to maintain the specified internal temperature criteria. However, the data also suggests a significant opportunity for passive temperature control in summer, provided that the response to daily external temperature variation can be controlled. The annual average RH is 86% and does not fluctuate significantly during the year. Dehumidification may be required to control moisture introduced to the space via ventilation, infiltration and latent gains from occupancy, particularly during the summer months.

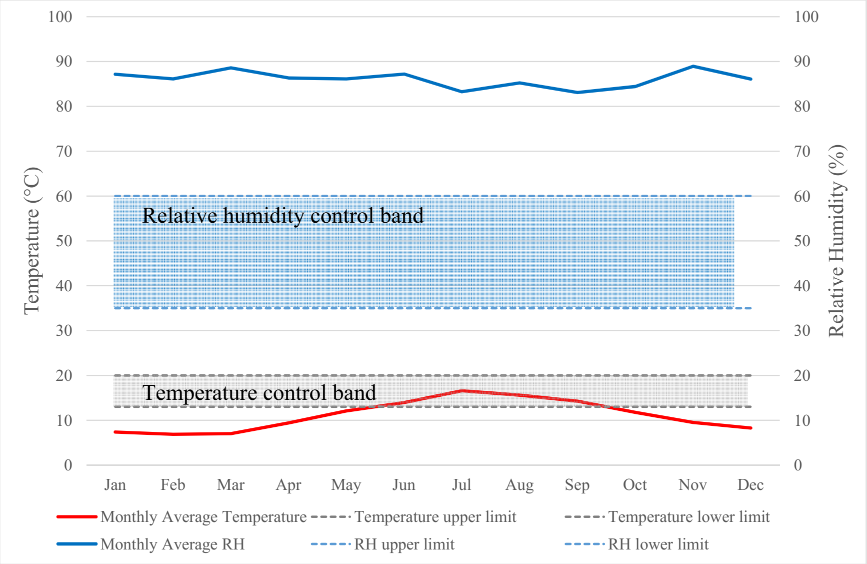

Fig. 1. Temperature and RH criteria for "mixed archives" and monthly average weather data for Plymouth

3.2 *Thermal modelling*

The proposed construction of the archive comprises an internal 300mm reinforced concrete skin. This provides the required 4 hour fire resistance recommended in PD5454: 2012 and is enclosed by a continuous layer of insulation. A rainscreen cladding is fixed back to the structure for external walls and the roof is constructed from an insulated flat roof system. Based on the results of a parametric study of thermal performance, the design of the archive has progressed based on the building fabric standards given in Table 1.

A thermal model for the archive was developed in IES Virtual Environment (Figure 2). To simulate the internal conditions within the archive, internal heat gains arising from the presence of people and the use of electric lighting need to be accounted for in the thermal model. Both archivists and visitor groups are anticipated to require access to the collection. Making provision for visitor groups in the design is an unusual requirement for this type of archival storage facility. Although the proposed archive tours are of short duration, the presence of people contributes sensible and latent gains to the space and has further implications for the ventilation system design. Heat gains from electrical lighting have been calculated based on an LED lighting installation with automated presence detection controls. An average infiltration rate of 0.022 ACH has been assumed. This is based on achieving a building envelope air permeability of 0.4 ACH at 50Pa (a standard previously achieved in the Hereford Archive and Repository that was designed to PassivHaus standards, as reported by Grant & Clarke). Ventilation to the archive incorporates CO_2 demand control.

Table 1. Archive building fabric performance standards

Element	U value (W/m²·K)
Roof	0.12
External Wall	0.18
Exposed Floor	0.18
Internal Floor	0.18

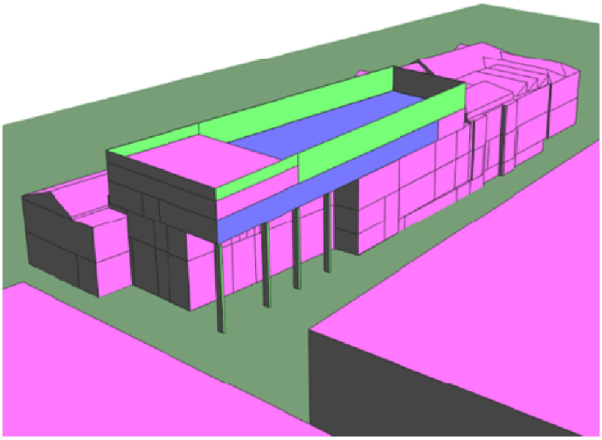

Fig. 2. Image of Plymouth Museum archive model geometry in IES Virtual Environment (second floor archive shown in blue)

The thermal performance of the archive was simulated using the Plymouth CIBSE TRY weather file.

3.3 *Results*

The air temperature profile within the archive without active heating, cooling or dehumidification (i.e. "free-running") is shown in Figure 3 alongside the external dry-bulb (DB) temperature. Summary statistics for the variation of temperature are given in Table 2. Four metrics are reported:

$\Delta T_{max,\ day}$: the maximum daily variation in air temperature.

$\Delta T_{max,\ week}$: the maximum weekly variation in air temperature.

$\Delta T_{avg,\ month}$: the magnitude of change in average internal air temperature from the preceding month.

$T_{avg,\ annual}$: the annual average internal air temperature.

Table 2. Summary statistics for thermal performance of the Plymouth Museum archive in free-running mode

Month	ΔTmax, day (°C)	ΔTmax, week (°C)	ΔTavg, month (°C)
Jan	0.30	0.64	0.37
Feb	0.29	0.65	0.87
Mar	0.30	0.51	0.08
Apr	0.31	0.72	0.72
May	0.37	1.08	1.78
Jun	0.32	0.76	1.07
Jul	0.33	0.85	2.12
Aug	0.29	0.51	1.11
Sep	0.29	0.62	0.63
Oct	0.28	0.77	1.39
Nov	0.30	0.83	2.16
Dec	0.30	0.61	1.29
Maximum	**0.37**	**1.08**	**2.16**
Annual average internal air temperature (Tavg, annual)			**15.4°C**

4 Discussion

The thermal modelling results demonstrate that an airtight, thermally massive construction enclosed with insulation is effective at isolating the case study archive from daily and seasonal variations in external temperature. The annual internal temperature profile shown in Figure 3 is approximately sinusoidal and falls within the specified temperature control bands of 13°C and 20°C for the majority of the year. This indicates significant potential for passive operation of the archive, thereby reducing energy use.

Daily fluctuations in internal temperature are sensitive to assumptions regarding the infiltration rate and internal gains. With respect to occupancy, this implies access to the archive should be restricted as much as reasonably possible in order to maintain a stable internal environment. It also highlights the benefits of specifying low-energy electrical lighting with appropriate occupancy controls. Infiltration has an impact on both the daily temperature and RH stability of the archive and the design should aim to reduce unwanted air leakage. In addition to reducing infiltration through appropriate detailing of the construction elements, consideration should also be given to providing entrance lobbies and sealing of services penetrations.

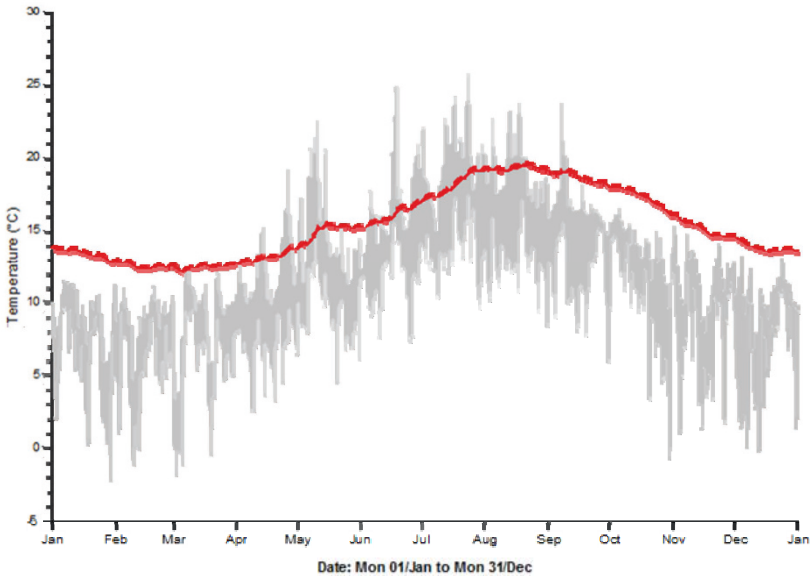

Fig. 3. Annual temperature profile of the archive in free-running mode (internal temperature shown in red, external temperature in grey)

The four metrics developed for assessing the thermal performance of archives in "free-running" mode can enable the performance of alternative design options to be compared as follows:

- The maximum daily and weekly variation in air temperature can be used to assess the thermal stability of the archive to short-term weather conditions and the possible impact of temperature fluctuations on the collection. It is the impact of changing temperatures on RH that is likely to be the concern for preservation: PD5454: 2012 notes that RH increases by approximately 3% for each 1°C decrease in temperature (and vice-versa) for small temperature differences (±5°C or less in a room at about 20°C).
- The magnitude of change in average internal air temperature from the preceding month and annual average internal temperature can be used to assess the potential for passive temperature control of the archive over longer time periods (i.e. in response to seasonal variations in external temperatures).

5 Conclusions

This paper has proposed four metrics that may be used for assessing the temperature stability of archives and demonstrated their application to a case study building. These metrics are assessed in "free-running" mode where passive operation is an integral part of the environmental design strategy. Future development of metrics for assessing the thermal performance of archives should consider:

- The selection of weather data used for assessing performance at the design stage. The impact of climate change should be included in the analysis of passive design options, given the intended longevity of archives and their collections.
- Assessment of dynamic variations in RH, including hygroscopic buffering by both construction materials and the items stored within the archive.
- The assessment of radiant temperatures within the archive and potential for air stratification. Air circulation may be required to ensure the air within the archive is well mixed.
- Monitoring and assessment of the actual operational performance of archives in terms of temperature and RH stability.

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Ont-EIR Framework to Deliver Sustainable Heritage Projects

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Abstract. Informed retrofitting and maintenance is recognised as a cornerstone of sustainable heritage buildings. Clients and the construction team are concerned with the delivery of projects that are within the timescale, budget, as well as energy efficient and environmentally friendly. Indeed, they are increasingly being challenged to deliver sustainability performance of heritage projects. Employer Information Requirements (EIR) is now seen as essential for in any successful heritage building delivery.

When designing a sustainable BIM project it has to be made sure that a complete and comprehensive EIR is delivered at the beginning of the project, in order to be able to produce a sustainable and energy efficient building, the EIR has to assure delivery of a full package of sustainable requirements for the construction project team, which in turn will allow them to produce a complete and correct BIM Execution Plan (BEP) that will be the basis upon which the whole construction process and definition of roles and responsibilities will be based.

This paper discusses the design and development of an Ontology-based, BIM-enabled framework for EIR, which will support clients of smart-heritage projects to define their requirements in terms of sustainability. It will investigate the innovative approaches and methods used to produce a complete, correct, and comprehensive EIR. This framework will enable the heritage team to capture, analyse, and translate these requirements and convert them into constructional terms understood by all stakeholders, which covers all aspects needed to produce a smart-heritage project. The intention of this study is to save time, effort and cost, and in the same time provide an informed basis for delivering a successful project.

Keywords: Heritage; smart; Sustainable; BIM

1 Introduction

Employer Information Requirements (EIR) is an important document in heritage projects for the information and instructions it holds for the creation, storage and transfer of the digital information when a building is delivered via BIM. (BSI, 2007. BS1192:2007). Designing a successful EIR is an important solution for managing the

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collaboration and integration process that is the main feature of the BIM process in heritage projects. Integration and collaboration are important for reducing the project overrun and cost, removing the non-value-added activities, encouraging collaboration, and increase client satisfaction (Sun and Aouad, 2000).

The need for a comprehensive EIR framework arises from the fact that many issues should be covered completely in the EIR to assure delivery of a full package of requirements for the construction project team, which in turn will allow them to produce a complete and correct BEP, that will be the basis upon which the whole construction process will be based.

The importance of the EIR documents is due to the variety of information that have to be addressed, this information includes management information, technical information, and commercial information, which involve: roles and responsibilities, definitions that will be essential during the construction process, organising the collaboration process between the different project team members, software issues, standards and guidance that will be used during the projects process, defining the construction process of the project in terms of phases, data drops and deliverables, in addition to defining project requirements that should be met during each phase and data drop.

The aim of this framework (OntEIR) which is an ontology based, BIM enabled framework for EIR in construction projects, which also include smart heritage projects, is to enable clients of these projects to answer the main questions of:

- what should be delivered in terms of projects requirements
- how will this information be delivered and managed which will include organizing the collaboration process of the BIM process
- when will this information be delivered in terms of clear data drops and time frames, and who will be involved in the delivery of this information, which includes the project team, in addition to definitions and standards and regulation issues.

OntEIR is a multi-disciplinary project that incorporates the Requirements Engineering (RE) method, which is a branch of systems engineering. The reason for this incorporation is due to the issues it addresses which are vital for OntEIR development, such as the desired properties and constraints of complex systems, organizations and process, through the RE approach in the analysis, refinement, and analysis of requirements.

The significance this research is in the final product which is a complete and comprehensive EIR, that will cover all the issues needed for a successful and sustainable heritage project in an easy and clear way to the clients.

2 Previous studies

Ontology and requirements engineering studies are not evident in construction, and more precisely in EIR, but there are researches on requirements specifications and requirement engineering in other fields such as systems engineering, for what it offers that field in improving the qualities of requirements, terms of correctness, completeness, and consistency, which will have great effects in saving time and cost (Kossmann et al, 2008, Kossmann and Odeh 2010).

OntoREM is a semi-automated methodology developed for creating requirements specifications for systems in less time and at reduced costs, while improving the quality of such specifications (Antonini et al, 2014), due to what it offers in the elicitation of the domain knowledge field, and the analysis and validation of the needs, goals and requirements with relevant stakeholders and domain experts. (Kossman and Odeh, 2010)

OntoREM was initially developed to capture and manage reference knowledge and concepts in the domain of RE, which will result in the development of high quality requirements for any specific application domains (Kossmann and Odeh, 2010)

The OntoREM metamodel was developed using OWL DL, and edited by the Protégé tool, according to the approach described by Noy et al (2000), based on this metamodel, more specific instances of OntoREM were created (Kossmann and Odeh, 2010)

OntoREM (Ontology-Driven Requirements Engineering Methodology) is a novel methodology developed in this area. It is the product of a joint project between the University of the West of England and Airbus. OntoREM has been applied in case studies in both aerospace industry and space missions, and was a success in both cases (Kossmann and Odeh, 2010). OntoREM was able to help in developing quality improvements for the generated requirements specification, it assisted in generating about 100% additional project and system requirements (Antonini et al, 2014)

Knowledge-driven methodology is what OntoREM mainly depends on opposed to the more widely used process-driven approach. The argument for that is because knowledge-driven requirements engineering is guided by both the process and knowledge about that process and the problem domain (Kossmann et al, 2008). During the knowledge-driven approach adopted by OntoREM, a set of workflows and associated activities are defined, driven by knowledge and ontologies, which will help in overcoming the problems associated by the process-driven approach of corrective rework, which causes additional costs and delays (Kossmann and Odeh, 2010)

OntoREM has been developed in the area of requirements engineering, which has gained a lot of attention in software engineering for what it has to offer in elicitation, refinement, and analysis of requirements. Requirements Engineering (RE), a branch of software engineering that deals with elicitation, refinement, analysis, etc. of software systems requirements gained a lot of attention in the academia as well as in the industry.

The main advantages of using domain ontologies in the context of OntoREM are that the analysis and re-usability of the specified domain knowledge including requirements is greatly enhanced which, in turn, allows for significant process time savings and increased quality of the data contained in the domain ontology in terms of correctness, completeness and consistency (Kossmann and Odeh, 2010).

This Requirements Engineering Methodology will be adopted in the OntEIR framework for what it has to offer in EIR in terms of Requirement Engineering, and the knowledge driven process, which is considered the best option for the EIR process

3 OntEIR Approach

The development of EIR can initially be a simple process map, on which key decision points that will take place through the construction process are identified, this process map is to ensure that the solution developed satisfies the business needs and defines in very broad terms the information that will be needed to make such decisions. According to the BIM plan of work, identifying the EIR for the project is the main phase, due to its importance in setting out the information required by the employer aligned to key decision points or project stages, and thus enabling suppliers to produce and initial BEP from which their proposed approach, capability and capacity can be evaluated, see figure [1]

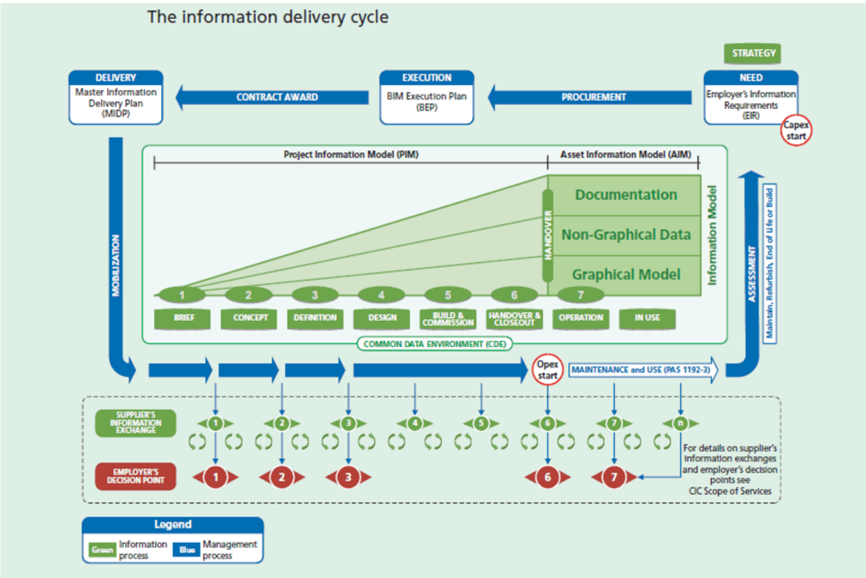

Figure 1: BIM Information Deliver Cycle (Adopted from PAS 1192-2:2013)

The amount of success in which the EIR is measured, is according to the degree in which it meets its purpose, therefore, the identification of this purpose should be done from the beginning of development of EIR. As studies have shown, inadequate, incomplete and ambiguous or inconsistent requirements have a significant impact on the quality of the project delivered (Assaf & Al-Hejji, 2006, Potts, 2008).

The OntEIR approach was designed to guide construction clients in defining and specifying Employers' Information Requirements (EIR) for construction projects. The Requirements Engineering (RE) Methodology was adopted in the development of OntEIR. EIR researchers have had little or no focus on RE system development, which is actually important if we are looking to develop a more client-oriented and more practical EIR, and despite the increasing interest in EIR, there is no research to identify the best practices in RE. Kossmann (2013) argues that 'requirements are detailed expressions of specific aspects of less detailed stakeholder needs'. They formalize relationships between the stakeholders or customers of a system, and the developers or suppliers of the system. 'A system here is defined as an integrating set of interacting elements; such as products, services, people, processes, hardware, software, firmware, and information that serves a defined purpose'.

OntEIR is an important solution for the integration and collaboration of processes and project team members. A comprehensive and clear EIR will have substantial benefits on the integration process in BIM projects. As suggested by this research, RE is necessary to develop user-oriented and a more practical EIR. Aouad and Arayici (2010) suggest that employing the appropriate requirements techniques will provide the following benefits:

- More practical systems
- Increased usability and ease of use
- Configurable systems
- Flexible and scalable systems
- Contribution towards closing the gap between the practitioners and the researchers

Due to the importance of defining accurate requirements, Employer Information Requirements should go through a series of an iterative process of requirements engineering that includes eliciting requirements, modelling and analysing requirements (Nuseibeh & Easterbrook, 2000). As described by Lamsweerde (2000), and Nuseibeh & Easterbrook (2000) RE includes the covering of the following activities:

• *Domain analysis*: the environment for the system-to-be is studied. The relevant stakeholders are identified and interviewed. Problems with the current system are discovered and opportunities for improvement are investigated. Objectives for the target system are identified.

• *Elicitation*: alternative models for the target system are analysed to meet the identified objectives. Requirements and assumptions on components of such models are identified. Scenarios could be involved to help in the elicitation process.

• *Negotiation and agreement*: alternative requirements and assumptions are evaluated; risks are analysed by the stakeholders; the best alternatives are selected.

• *Specification*: requirements and assumptions are formulated precisely.

• *Specification analysis*: the specifications are checked for problems such as incompleteness, inconsistency, etc. and for feasibility.

• *Documentation*: various decisions made during the requirements engineering process are documented together with the underlying rationale and assumptions.

• *Evolution*: requirements are modified to accommodate corrections, environmental changes, or new objectives.

The OntEIR framework will have the aim to facilitate the identification, clarification, and representation of employer requirements for heritage projects. The initial framework developing process will go through a series of stages that attempt to define functions, classify functions, and develop function relations based on the literature review and interviews conducted.

1- Generating high-level goals:

Using mind mapping, the problem domain will be elicited and analysed, the data visualized in the mind map is actually a representation of elicitation and analysis of requirements done with relevant stakeholders and domain experts via interviews. High level needs are formulated as result.

The visualization of the initial EIR framework will be done through mind mapping that consists of all aspects of the EIR which are broken down to reach high level goals, this will help us in determining and generating requirements more clear and precise, and help the employer body in determining their more specific requirements and concerns regarding the project.

The analysis of the EIR mainly divides the domain into two parts: static information and dynamic information

- Dynamic requirements (which include the commercial information):

This set of requirements looks at the process as different stages; each stage having its own set of requirements and information to be delivered, it includes details on the Client's strategic purpose, the defined deliverables and a competence assessment for those looking to tender the heritage project and demonstrate their ability to deliver the requirements of the EIR

These requirements are more specific to the construction phases, what is required by the project team to be delivering at each phase, who will be involved, and how will that be done, they will answer the major part of the plain language questions. These requirements include:

- Main outcome of the data drop
- Project requirements for each data drop
- Level of detail, and level of information (as defined in the management information) for each data drop
- Actors
- Standards and guidance needed
- Software formats to be used
- Security

- The employer should specify the different stages he would prefer the process to go through (data drops).
- The employer should define the different levels of development, and levels of information, which will be delivered at the different data drops.
- Software platforms that will be used during the BIM process including version numbers that will be used by the supply chain to deliver the project, including any particular constraints set by the employer on the size of model files.
- Standards, Protocols, and regulations to be used during the process.
- Coordination and clash detection
- Defining roles and responsibilities of the BIM team

Static information are more of a definitive nature. In a more specific sense, and as discussed previously, static requirements include the management information and the technical information; Management will detail high-level roles and responsibilities, standards, data security, the key decision points and the information to be available at each one. Technical will cover things like information format and file types, the minimum Levels of Definition at each stage and the software platforms to be used for exchanging information. For Clients in the public sector, that doesn't mean you have to endorse a particular vendor. It could be stating your preference for email or explaining the common data environment you will be using.

In general goals should cover these issues:

- The employer should specify the different stages he would prefer the process to go through, data drops, and define the deliverables for each drop.
- The employer should define the different levels of development (LOD), and levels of information (LOI), which will be delivered at the different data drops.
- Software platforms that will be used during the HBIM process including version numbers that will be used by the supply chain to deliver the project, including any particular constraints set by the employer on the size of model files.
- Standards, Protocols, and regulations to be used during the process.
- Coordination and clash detection

Management requirements will detail high-level roles and responsibilities, standards, data security, the key decision points and the information to be available at each one. Technical requirements will cover issues like information format and file types, the minimum Levels of Definition at each stage and the software platforms to be used for exchanging information. Figure 2 shows a mind map of the analysed EIR information

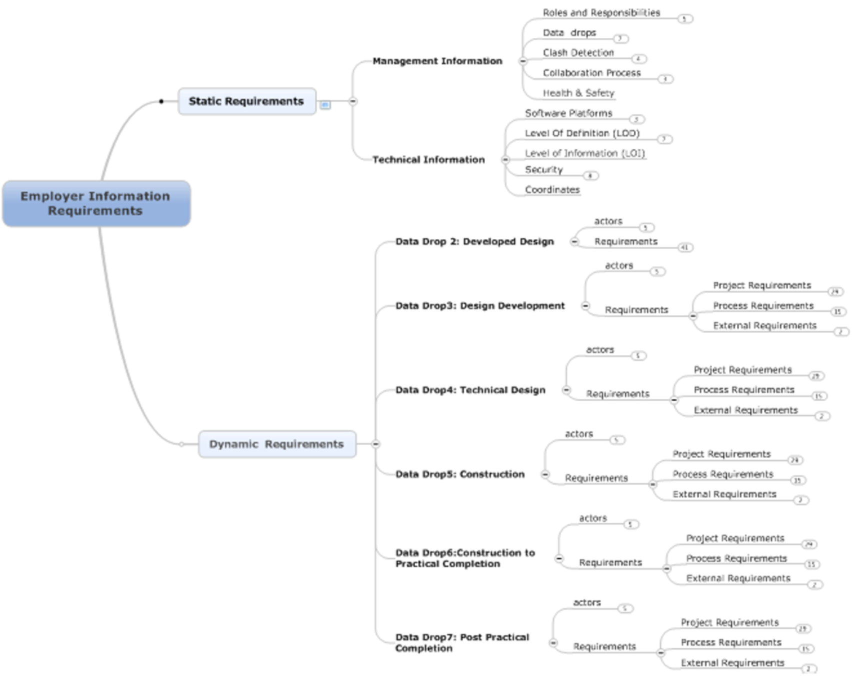

Figure 2: EIR information

2- Requirement specification

After reached root goals in the goal hierarchy generated by the mind map, requirements are used where relevant. In case the requirements do not cover a root goal, then new requirements will have to be generated.

3- Requirements validation

Goals generated from mind map will be validated with relevant stakeholders and domain experts in the construction industry.

After reaching the mind map that holds the necessary information: EIR domain knowledge, problem domain knowledge, solution domain knowledge, and stakeholder information, ontology will be applied to develop OntEIR, to create an ontology-based system for EIRs, which will create quality employer information requirements in terms of consistency, completeness, correctness, traceability, and the ability to be instantiated to any construction project.

The approach for accomplishing should have the ability to classify and prioritize the requirements, determine the relations between them and deliver them in terms understandable for the construction team

3.1 *Re-using Ontologies*

The re-use of ontologies enables us to save time and effort, because of the use of ontologies that have already been validated in the field of research through practical use in applications. The OntoREM is an ontology-driven requirements engineering methodology that will be re-used in this research.

The reason for the re-use of this particular requirements engineering methodology is due for what it has to offer in the area of requirements engineering in the field of EIR. It will facilitate the process of analysis and requirements elicitation, and due to the fact that knowledge-driven requirements engineering which is the approach of OntoREM, is the most suitable requirements engineering approaches for the elicitation and specification of employer information requirements, that is because in order to be able to plan a successful construction project you should acquire knowledge of both the domain and the process of that domain, which is what OntEIR will be doing.

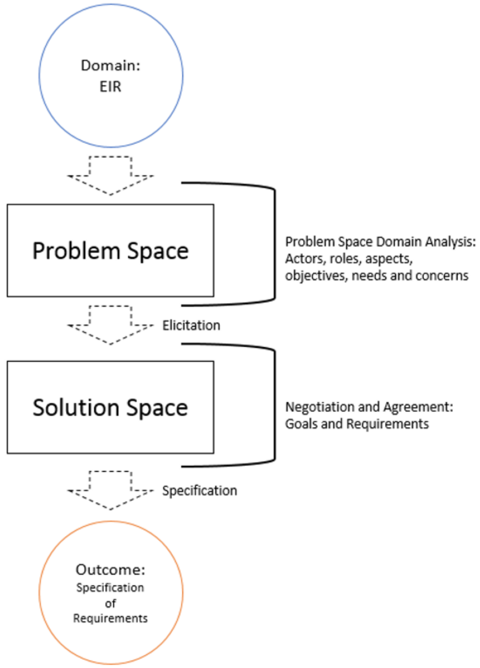

Figure 3: Requirements Engineering Methodology aproach

The Requirements Engineering methodology mainly divides the domain into two aspects: the input and the output, what is meant by the ‘input’ is the ‘problem space’, while the ‘solution space’ being ‘output’. The problem space is all the relevant knowledge of the domain, including its main actors and their roles, aspects, objectives, needs and concerns, on the other hand, the solution space is the outcome of the analysis of the problem space, and holds the most important outcome of the methodology, which is the requirements specifications, as illustrated in fig [3] [Kossmann and Odeh, 2010].

4 OntEIR

As mentioned before the Ontology-driven Requirements Engineering Methodology is adopted in creating OntEIR. Due to the nature of this methodology to be a knowledge-driven methodology, information and knowledge, regarding the domain (EIR) had to be gathered, which will be crucial for the forming of the requirements for the projects. This information includes the roles and responsibilities, life cycle phases, workflows, concerns and definitions will be the basis platform in creating the OntEIR. When applying the Ontology Requirements Engineering Methodology, a pattern can be seen in using this information, which will help in eliciting additional information, which will all assist in the specification of EIR requirements which is the end results and the purpose of this framework.

The domain is mainly divided into two aspects: the input and the output, what is meant by the input is the problem space, and the solution space is the output. The problem space is all the relevant knowledge of the domain, including its needs and concerns, the solution space is what holds the most important outcome of the methodology, which is the requirements specifications [Kossmann and Odeh, 2010].

In order for requirements to be specified, EIR will have to go through a series of phases, which starts with the elicitation, which will result in generating high level goals, those goals will be the basis for specifying the requirements, which at the end will be validated. Figure (4) below illustrates the process in which requirements go through before being reached according to the OntEIR approach.

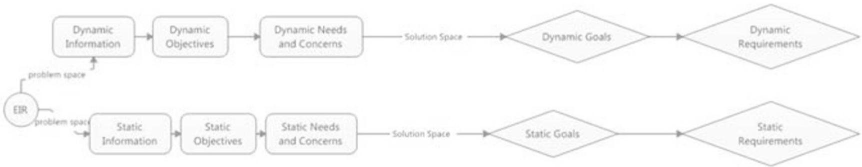

Figure 4: requirements elicitation in OntEIR

The process of identifying the requirements goes through a series of iterative phases, the process involves the identification of different concepts, and the relationships between them, feeding them in the OntEIR, in both the problem space and the solution spaces, in order to end up with clearly specified Employer Information Requirements.

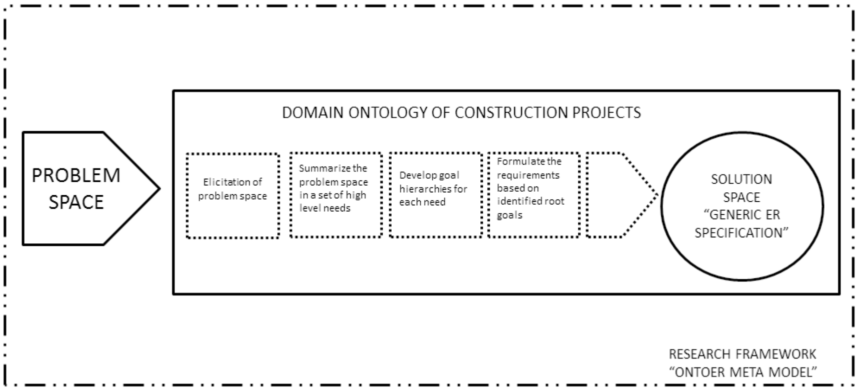

Figure 5: OntEIR Meta Model

5 Concluding remarks

This on-going and novel study of creating an ontology-based, BIM-enabled framework for defining EIRs will have potential in delivering a better defined, comprehensive and consistent EIR, on which the BEP will build on. Above all, a clearer EIR will lead to a more successful construction project, which includes heritage and smart heritage projects.

The success of OntEIR is due to following characteristics:

- Stakeholder and expert contribution to the study assists in understanding the need in construction projects, including smart heitage, which leads to defining better requirements in OntEIR to bridge the gap between clients and execution in construction projects;
- OntEIR is able to cover all aspects of a well and complete defined EIR as specified in PAS 1192:2, in a clear and understandable form for both the employer and the project team.
- Hierarchy and tractability offered by ontology will make it possible for OntEIR to be instantiated for different types of projects;
- OntEIR is able to clearly answer the plain language questions and requirements that are to be met before moving from one stage to the other;
- OntEIR will assist employers defining clear and adequate requirements, and at the same time will be easy to be interpreted by the design team and translated into building terms, and thus create better BEP;
- OntEIR saves time in specifying requirements for projects and gives excellent results in terms of quality and consistency.

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Heritage Preservation within public open spaces: the case of Qabel Street (Old Jeddah) Spacious Experience

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Abstract. Building Information Modeling provides a solid ground for historical areas documentation, where a virtual experience of historic buildings is digitally constructed in order to maintain the built environment through its entire lifecycle. Jeddah Old Balad area, especially "Old Hajj Road", is considered to be the core of heritage preservation. Therefore, this paper elaborates on a platform demonstrating the potential of combining big data for main corridor in Old Balad by using GIS server; In addition to people reflections within outdoor spaces via smart sensors while experiencing the variety of urban features of the area. Therefore, the aim of this paper is to give an overview of people responsiveness, as well as surveying and representation of spacious data in order to support the process of further integration between HBIM and GIS tools to maximize the use of built heritage resources used for creating, conserving, documenting, and managing information which has a great impact on touristic and commercial activities within the case of Qabel Street. The study aims to strengthen the relation between sustainable developments in this area within the explicit constraints of architectural heritage preservation.

Keywords: Historical Paths; Sustainable developments; HBIM; Smart Indicators; Sensors

1 Introduction:

Building Information Modeling provides a solid ground for historical areas documentation, where a virtual experience of historic buildings is digitally constructed in order to maintain the built environment through its entire lifecycle. Models have been constructed to enhance historic building information modeling (HBIM), such systems represent an extremely strong paradigm within architectural heritage that can be used for creating, conserving, documenting, and managing complete engineering drawings as well as adopted information. Therefore, the aim of this paper is to give an overview of people responsiveness in Jeddah heritage areas of Old Balad corridor by using GIS server; as well as surveying and representation of

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spacious data in order to support the process of further integration between Big Data, HBIM and GIS tools to maximize the use of built heritage resources in order to support the process of further integration between variety of factors and demonstrate how the complexity of built heritage resources can be dealt with.

2 Research Methodology:

The structure of the paper starts with elaboration on the importance of big data modeling in heritage conservation and previous models applied. This will be followed by a brief historical overview of the area under discussion. Secondly a detailed demonstration of existing of Qabel Street, the main corridor in old Balad via GIS Data analysis for existing urban fabric. Finally, results are discussed based on people reflections within outdoor spaces via smart sensors while experiencing the variety of urban features of the area, based on these recommendations for future plans for preserving the quality of the spaces will be suggested.

3 Historical Areas Documentation Approaches:

Building Information Modeling provides a solid ground for historical areas documentation, where a virtual experience of historic buildings is digitally constructed. In the context of rapid technology development, the theory of using building information modeling (BIM) has been used in several historic places as presented by N. Megahed, 2013. With BIM technology, several virtual model of a historic building can be digitally constructed in order to maintain the building through its entire lifecycle, including demolition. Specific work has been done by A. Baik et al.2013 and 2015, including documentation for existing architectural historical richness and details have been done under remote sensing techniques and spatial considerations. Such studies present a theoretical framework that has been constructed as a guide for the research done in this paper to enhance the understanding of the different aspects of historic preservation and management through a smart open platform in old Balad Area. The focus of the study will be related to urban features in outdoor spaces affecting people reactions towards the experience they live on a specific route in Old Jeddah.

3.1 Jeddah Old Balad Heritage area:

Saudi Government as well as public awareness do realize the importance of preserving the Saudi culture as well architectural heritage. In 2014, Historic Jeddah was considered as one of UNESCO's World Heritage Sites. Accordingly, the area was divided into subzones regarding to the historical value as can be seen in figure 1, Samir, A., 1986.

Jeddah municipality is concerned with preservation areas within old Jeddah districts as per the development projects conserved with preservation of old Balad historical sites, further details are available on the websites: https://www.jeddah.gov.sa/Jeddah/HistoricalPlaces/Districts/index.php https://www.jeddah.gov.sa/Business/LocalPlanning/HistoricalJeddah/index.php.

The Nominated Property (NP) is the oldest urban area of Jeddah city, which contains a group of urban and archaeological buildings characterized by their historical, architectural and urban value and importance represented on fig.1. Buffer Zone (BZ 1 and 2): Urban areas that surround the Nominated Property and represent the extension of urban areas and includes a range of activities. The biggest section of the street (BZ3 and BZ4) includes denser areas but with urban functions less dense. Representation of the developments done are presented in “Conservation of Jeddah Old Town Project Brief”, Agha Khan Projects award, 2013.

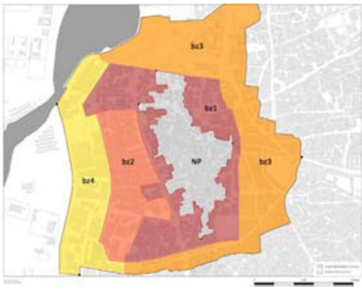

Fig. 1. Old Balad heritage area; zones; https://www.jeddah.gov.sa/Business/LocalPlanning/HistoricalJeddah/pdf/English/5.pdf

3.2 Qabel Street Historical Background:

Qabel Street or "Old Hajj Road" is one of the most important Jeddah's streets both in the past and recently. It locates in Historic Jeddah "Al Balad" districts in the heart of Jeddah city in Kingdom of Saudi Arabia. Because of its location, Old Jeddah was used as a port for the Holy Makkah facilitating regional commerce as well as receiving pilgrims. Qabel Street acted as the main path of pilgrims, as cited in http://www.sauditourism.sa/en/Explore/Regions/Mecca/Jeddah/Pages/j-9.aspx.The street locates within two of old Jeddah's neighborhoods which are Harat AlYaman to the south and Harat Almazloum to the north. Qabel Street extends from King Abdulaziz Road to the west till Old Makah Road to the east and bisected by Al Dahab Road, with total length about 700m as can be seen in fig. 2 demonstrated in https://www.scta.gov.sa/en/Heritage/Pages/HeritageSites.aspx. The street is divided into 3 sections, the western extension Al Mahmal Plaza, the second section lays between King Abdulaziz Road and Al Dahab Road, the third section from Al Dahab Road till Old Makah Road.

Fig. 2. Qabel Street, Main corridor; "Old Hajj Road" heritage area, Jeddah.

4 Urban and Architectural Analysis for Old Hajj Road, Qabel Street:

The Architectural Features and Urban Details have been cited under different researches done recently by Samaa B., 2015; Hossam B., 2016. Demonstrations for Data gathered along the built environment Qabel Street, Main Corridor in Old Balad, Jeddah is relevant to the spatial characteristics is presented in this paper by integrating GIS server; which will allow the further integration of People responsiveness relevant to specified routes data compilation and analysis for the following features:

4.1 Uses &Activities

Activities densities can be detected in fig. 3 representing the following percentages: 74.4% of the buildings along the street is for commercial activities for closes, bags and gold. 1.8% is for the religious uses, 22.6% is for residential uses, 0.6% offices and 0.6% is vacant lands. The street encompasses a group of the oldest and most famous souq in Jeddah like Alalawi, Albadw, ALgamee souq.

Fig. 3. Commercial versus residential occupancy along Qabel Street, Main corridor, *(by Authors).*

4.2 Buildings' Quality

Buildings with good quality concentrated in the western part of the street which considered as the new high rise buildings which represents 22.6% of the buildings, to the east of the street concentrates the bad and moderate buildings with percentage 75.6% of the buildings and some of those buildings are historic ones with especial importance, as per fig. 4.

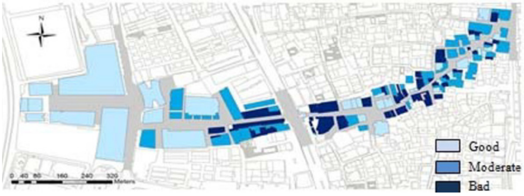

Fig. 4. Building status overlooking along Qabel Street, Main corridor, *(by Authors)*.

4.3 Architecture Characteristics

The analysis of gathered data demonstrates that 26.2% of the buildings along the street are historical almost all of them concentrate in the eastern part of the street fig. 5. Nevertheless, the value of those buildings most of them requires restoration, follows some examples of those historic buildings in fig. 8.

Fig. 5. Historical Buildings Existence on the eastern part of Qabel Street, Main corridor, *(by Authors)*.

A Okasha Mosque old and currently elevated entranc B. Nassif House

Fig. 6. Some of the existing historical Buidings along Qabel Street, (by Authors).

4.4 Street Network

Qabel street is a pedestrian pathway and intersected with two main streets, King Abdulaziz street by surface intersection and Al Dahab street through a pedestrian tunnel (C) as can be seen from points A, B, C and D as per figure 7. It intersects also with a secondary street Al abdarous street with surface intersection with other streets intersecting with Qabel street are pedestrian alleys, figure 10 shows respective views of selected nodes.

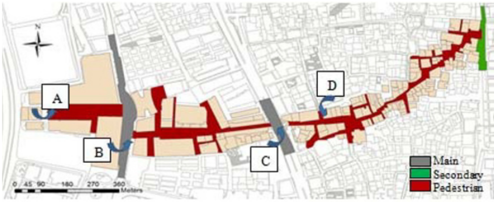

Fig.7. Street Network Intersecting Qabel Street, Main corridor, (by Authors).

A Souq Al Dahab B Gateway for Qabel Street C Pedestrian Tunnel D Typical Pedestrian Souq

Fig. 8. Respective views of selected intersections along Qabel Street, *(by Authors).*

4.5 Streets' Quality and Paving

Street Paving's status can be seen from fig. 9, the quality of the streets ranges between moderate to bad

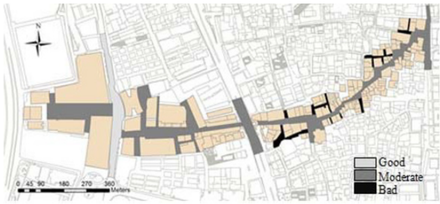

Fig. 9. Streets and Paving's Quality, along Qabel Street, (*by Authors).*

The finishing of Qabel street and other pedestrian allays is cobble stone and for the main and secondary streets are Asphalt, Al Mahmal plaza from tiles, as per fig.10.

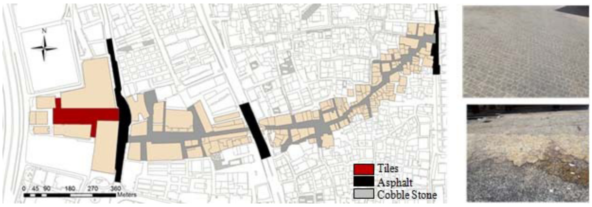

Fig. 10. Street and Paving Status along Qabel Street, *(by Authors).*

5 Spatial Responsiveness Indicators

While Experiencing the journey by several pedestrians that re really enjoying The main demonstrated responses against stress points indicate the change of normal responses, causes are documented via cam recording and tracking specific site location via GPS location, tools and techniques adopted by Taha et.al. 2012 and 2013; A.Nayer, 2015. The Results detected according to data measured gives indications to people responses, KREIBIG, S.D.2010. GIS Data representations provide for the existing status of urban spaces in the specified location where spatial features are explicitly described according to the above steps of the research produces in the first part under section 4. Data Gathering and compilation is verified according to the adopted methods in respective research done by the author in selected location on Jeddah to meet similar environment, public interest as well as developments targeted by decision makers, A.Nayer, 2016.

Table 1. Participants stress levels experienced alond their walk along Qabel Street as indicated on figures

Main Nodes Stress detected	Urban Features	Average fig. 14*d*	Participant (*1*) fig. 14*a*	Participant (2) fig. 14*b*	Participant (*3*) fig. 14*c*
Node (A) , fig. 9	Plaza	1	1	1	2
Node (A'), fig. 7	Mosque	3	3	3	4
Node (B) , fig. 9	Gateway	3	3	3	4
Node (B') , fig. 7	Plaza	3	3	3	4
Node (C) , fig. 9	Tunnel	3	3	3	4
Node (D) , fig. 9	Market	3	3	5	6

Selected Participants are three middle aged females interested in historical environment as well as regularly visiting the mentioned sites; they are all under the same moderate climate conditions and timing on the evening of weekend. Stress levels are interpreted as heat mapping indications on figure 11 a, b, c. Overall representation on fig.11d. Analysis of the findings presented in table 1, is performed through three main steps:

- Data analysis from collected computing wearable devices.
- Benchmarking against actual surveyed case presented on GIS mapping.
- Explicit listing for prospect solution suggested for targeted developments

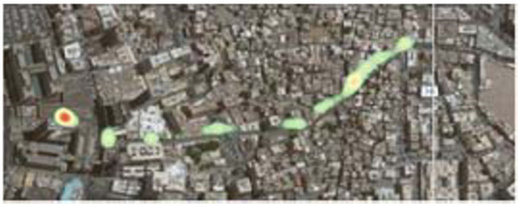

Fig. 11a. Participant (1) Heat Map detecting Stress Level along Kabel Street, (Sensors data analysis, by Authors).

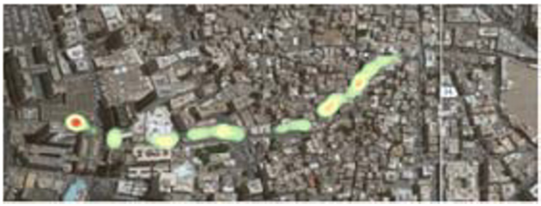

Fig. 11b.Participant (2) Heat Map detecting Stress Level along Kabel Street, (Sensors data analysis, by Authors)

Fig. 11c. Participant (3) Heat Map detecting Stress Level along Kabel Street, (Sensors data analysis, by Authors).

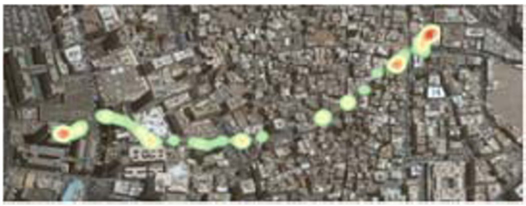

Fig. 11d. Overall participants 1, 2 & 3; Heat Map compiling Stress Level along Kabel Street, (Sensors data analysis, by Authors).

6 Discussion

The findings indicate the expected impact on touristic and commercial activities within the case of Qabel Street. The study provides a holistic overview that strengthen the relation between future sustainable developments in this area within the explicit constraints of architectural heritage preservation.

6.1 *Investigations and Surveys*

The analysis of gathered data demonstrates detected points were specific remedies should be attended to in terms of spatial solutions. Parallel investigations for people responses as well as physical surveys provide for a complete image of working for the public best involvement to enhance the experience in open spaces on Qabel Street.

Stress levels (as indicators to participants Comfort levels)	
High Stress levels	(due to unsafe street crossings at Node A, B, C)
Medium Stress Levels	(due to increasing in crowed density and path features Node A’, B’)
Minimum Stress level	(due to regular shopping and market activities)

6.2 *Potential of Developments*

Suggestions for resolving major points of stress along the Qabel Street will encourage safe pedestrian accessibility, as well as preserving the built environment in the historical area of Old Balad. Crowd management and Street Crossings should be handled in terms of facilitating the intersections between pedestrian paths as well as providing for required mobility for services while comparing node B and Node C.

Encouraging Public services and enhancing quality of spatial features is also required while checking the plaza sitting areas at node A and D for commercial purposes while the activities on nodes A’ B’ have purpose of preserving historical and cultural built environment.

7 Conclusion

Throughout Date represented in this research, we notice the importance of integrating the public responses in the process of Decision making, in terms of potential developments within existing urban heritage areas especially in Old Balad, Jeddah. Modeling techniques adopted allow for possible integration of variety of data typology by working under GIS Server. Therefore, the work presented highlights the importance of modelling heritage patterns as well as people responsiveness, by integrating surveyed data along with representation of spacious features under a digital environment, in order to support the process of further integration between HBIM and GIS tools to maximize the use of built heritage resources used for creating, conserving, documenting, and managing information.

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The Potential of Living Labs for Smart Heritage Building Adaptation

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Abstract. This paper examines: smart buildings as part of 'smart cities'; the particular challenges of heritage buildings; whether smart heritage buildings have any specific characteristics; the lack of data to inform appropriate refurbishment and retrofit; the emerging potential of technologies to engage people in acquiring that data and build bridges towards smart heritage, so easing the task of sustaining heritage buildings for the benefit of current and future generations; and 'Living Labs' as a key enabler. It is increasingly argued that there is a need to involve citizens in city development, so urban areas may be rendered more suitable to their needs and social problems be prevented. Meanwhile it is held that the value and significance of Heritage buildings and landscapes needs to be maintained, despite increasing pressures to adapt all building stock to address climate change and reduce increasingly expensive energy use. To convincingly engage citizens, such adaptation needs to enhance rather than reduce quality of life for users. Over the last decade there has been a move to repeated post-occupancy evaluation (POE), including some heritage building stocks, to ensure these goals continue to be achieved. Yet it can be argued that the number of such POE studies is limited by shortages of expertise, to the extent that in most cases we still lack sufficient data about the existing building stock, and in particular Heritage buildings, to make reliably informed judgements on suitable adaptation and mitigation measures. Simultaneously the sustainable transformation of Heritage buildings and landscapes into Smart Heritage can be held to be a key component in the metamorphosis of existing cities into Smart Cities. Thus this paper examines how Living Lab processes of engagement may deliver innovative approaches to POE, and thus support the scaling and speeding up of the transformation of Heritage into Smart Heritage.

Keywords: Living Labs; Smart Cities; Smart Heritage; Post Occupancy Evaluation; Community

1 Smart Cities

Cities, it is argued, will have become 'smart' "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (Caragliu et al 2011). Saunders &Baeck(2015)show that cities create wealth and opportunity, but also acute

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DOI 10.1007/978-3-319-48725-0_5

challenges in transport, infrastructure, and safety. They claim ‘smart city’ ideas offer solutions (although warning of exaggerated claims both for and against), arguing that combinations of “sensors, data and advanced computing has promised to speed up information flows, reduce waste and sharply improve how efficiently resources can be managed.” To this end Juujärvi & Pesso (2013) identify a general and “growing trend to involve citizens in city development to make urban areas more suitable to their needs and prevent social problems”, and others argue that: co-creation enables both users and producers to become active innovation agents (Platoniq 2015); the “social value of co-creation is fuelled by aspirations for longer term, humanistic, and more sustainable ways of living” (Pallot&Pawar 2012).Saunders & Baeck(op.cit) claim there are five elements necessary to achieve the goals of a smart city. These are to establish: ‘a civic innovation lab using collaborative technologies; open data and open platforms to mobilise collective knowledge; that human behavior is as important as technology; investment in smart people, not just technology; collaborative technologies for all parts of society.’ It is these last two points that this paper particularly addresses; how occupants of heritage buildings may engage with collaborative technologies, and thus both augment their efficacy and enhance their wellbeing, while improving the sustainability of the heritage fabric itself.

2 Smart Buildings

Many ‘smart buildings’ definitions narrowly focus on enhanced building management systems in new constructions. Yet smart buildings should be defined as key ingredients for the development of smart cities. Buckman et al (2014)suggest that the ‘upper bound of the Smart Building is defined by (the future development of) the predictive building’. Philips “Digital Living Room” project first described ‘Ambient Intelligence’ arguing that an ‘unconscious tool becomes an extension of the user’ (Epstein 1998). The key elements were that ICT devices (those we now term IoT) should be pervasive, invisible, but above all predictive in anticipating and responding to people’s needs in any environment, perhaps via predefined user profiles. This takes the focus towards the building as a facilitator, more than a moderator of the external conditions, that supports an alert, proactive supportive and responsive environment making ‘our whole lives relaxed and enjoyable’ (Crutzen, C, 2006). Siemens (2010) argue that smart buildings will only be sustainable long-term via “synergies between energy efficiency, comfort and safety and security … solutions that turn buildings into living organisms: networked, intelligent, sensitive and adaptable”. For the technologies to become sufficiently pervasive, the cost must be low and operation reliable. Yet it is evident that it will be much more difficult to modify existing buildings to form such ‘organisms’. This is the larger challenge, since existing buildings, and in particular heritage buildings and their contexts, cannot sustainably be subject to wholesale clearance and replacement, so need to be modified without damaging their qualities.

3 Some reasons why existing and heritage buildings need to be enhanced

It is regularly stated in the UK that over 80% of current buildings will still be in use in 2050, and in need of substantial retrofit just to meet carbon and energy targets (Dowson et al 2012).There is close correlation between levels of greenhouse gas emitted from buildings, and levels of demand, supply and source of energy (U.N.E.P. 2009). A narrow UK measure "lists" approximately 2% of that stockas significant heritage, with many already identified at risk, without addressing future climate change challenges (Brightman 2012). A broader UK measure identifies over 20% as dating from pre 1919, and in Wales that figure rises to 34%, amongst the highest proportion of heritage buildings in Europe. At over 25%, Wales also has double the UK average of households in fuel poverty, with a consequential reduced quality of life (Howarth2010). Historic England argue viable economic uses are needed to fund: initial refurbishment; repayment of investment; and income enough for maintenance in the long-term (Brennan & Tomback 2013).So 'heritage buildings' pose major challenges in affording and achieving adequate measurable retrofit, while simultaneously conserving their value and significance, and maintaining curtilages and broader landscape settings. Equally adaptation needs to steadily enhance, not reduce wellbeing, in order to convincingly engage citizens, Some enhancement may come via broader employment.Rypkema (2008) argues historic buildings are essential for the revitalisationof city centres, and that in "Europe, historic rehabilitation creates 16.5% more jobs than new construction, and every direct job in the cultural heritage sector creates 26.7 indirect jobs," far more than many other sectors.

4 A dearth of information on the current performance of existing and heritage buildings

Sustainable refurbishment must avoid waste, but there is little measured data on how occupied older buildings perform. Some, e.g. terraces, were originally standardised, but now each is probably unique via later ad hoc upgrades, alterations and structural movement. Over the last decade there has been a move to obtain irregular and occasionally repeated 'snap-shot' post-occupancy evaluations (POE), (including some heritage building stocks,) in order to determine progress towards key targets. Such POE involves both quantitative and qualitative measures. Yet it can be argued that despite the need for much more extensive POE studies, numbers are limited by shortages and the cost of expertise. The UK is said to have over 26 million buildings. A tiny percentage of that stock has been evaluated. Many evaluations remain proprietary and are not published. So in most cases we still lack sufficient data about the existing building stock, and in particular Heritage buildings, to make reliably informed judgements on suitable adaptation and mitigation measures.

5 Other means of evaluation are needed

Now real-time quantitative data and to some extent qualitative data collection is increasingly affordable, due to the advent of smartphones and low cost sensors. Leading members of ICOMOS (Jigyasu2105) also identify needs for "developing innovative low cost and culturally sensitive technology for mitigating disaster risks to cultural heritage". Such monitoring is the first stage in establishing a future alert, proactive supportive and responsive environment. We need to discover what is happening over time, in order to make reliable predictions; to use "modern technologies to continuously monitor the condition and operation of infrastructure and to intervene before problems arise and to develop better solutions for the future"(AGI 2015).Predictions may then be used to better inform user actions, or in the longer term automatically matched to user profiles to create the 'sensible and adaptive environments' that may in future give rise to smart buildings and smart heritage (NRCC 2010; Herbert et al 2008).

6 How to engageusers in predicting performance of, and managing heritage buildings

The performance of a building depends not only on its fabric and systems, but also on the way it is used. Human behavior can massively affect the performance of ostensibly identical buildings or dwellings. Yet much current real-time data collection remains building fabric focused or room centric. Therefore some, e.g. Pedersen &Petersen(2015),now argue that person centric data collection leads to more useful analysis. It is also claimed that people have more time to engage via ICT, to the extent that it is creating a 'cognitive surplus' that can be tapped into (Oomen&Aroyo2011). Kim &Paulos (2010)identified that environmental data is not generally perceived as private, and that "data sharing can persuade behavior change", but that people remain disengaged with real-time data unless it is linked to causes and solutions, so empowering them. Users should be engaged in meaningful co-design of their interaction with the environment, and the level of on demand or automated response they wish. Such engagement is core to the Australia ICOMOS Charter (2013), which states "groups and individuals with associations with the place as well as those involved in its management should be provided with opportunities to contribute to and participate in identifying and understanding the cultural significance of the place. Where appropriate they should also have opportunities to participate in its conservation and management."Steele and Clarke(2012)claim that much can be obtained with occupant engagement in participatory sensing via automated apps on individual smartphones… "it enables and creates potential personalization via two-way communication with the occupants of a space where occupants become active participants in monitoring of the environment, collecting data that affects them and receiving meaningful analysis or updates in return". They conclude that the most benefit can be gained from "a composite model that allows the collection of both fixed-infrastructure sensor based data and person-centric data collection through mobile devices", ie deploying "smartphone-internal sensors, smartphone-external sensors and also infrastructure-fixed sensors". To enhance wellbeing Clarke and Steele (2014) suggest that "capabilities are further extended with the addition of ubiquitous external sensing components such as activity monitoring and other wearable consumer health sensors." Where challenges arise in sensor data analysis they suggest that "human-sensing and feedback allows for validation to be performed by requesting subjective details or clarification of the data collected". Heritage buildings may demand greater reliance on person centric mobile sensors than fixed, since mobile sensors are less intrusive, and potentially less damaging to the heritage structure, and may capture data in places that cannot be directly linked to wired or wireless networks, for later upload.

Fig. 1. A variety of forms of non-destructive measurement, and real-time data capture at the CADW cottage

7 Recent relevant experience in Cardiff Metropolitan University, Wales, UK

In 2004 Johnson Controls commenced a funded research project to study how workers used the space in open plan offices, and analyse the usage of meeting rooms. This was the first 'Living Lab' project of which the author had direct practical experience, advising on the use of RFID to track the workers in headquarters buildings near London, and in the USA. Workers voluntarily wore RFID badges. There were RFID readers in the reception, in each meeting room, and at each hotdesk, enabling the use of space to studied in real-time. This system enabled unpopular desk-choices to be identified, and that space then to be reassigned to other more beneficial use. Users benefitted by being able to pre-book desk space prior to arrival, find out who else was around, and remotely check the current occupancy and thus availability of meeting rooms. It was also predicted that better advance prediction of building and zonal occupancy levels enables more targeted use of building systems, reducing the blanket energy consumption incurred by running all areas at targeted temperatures, just in case.

The author and other colleagues have since used fixed infrastructure monitoring of existing and heritage buildings for several years. One study for the Welsh heritage organization CADW has involved measuring a traditional pre-1919 miner's cottage since early 2014. Every form of measurement was trialled, including the collection and analysis of data from sensors throughout the building, and through the solid stonework walls. All the methods used in that trial have proved highly expensive. Therefore a more recent project explored how costs could be lowered enough to enable widespread installation, using the very low cost computer, the 'Raspberry Pi' as a data logger with low cost cable connected sensors. This project involved applying pre-cast pre-dried hemp-lime panels to internally insulate a solid stonework external wall in a heritage cottage in Wales. Thin 12 volt heated panels (developed by Specific, Swansea University) were also applied to the wall, one between the insulation and the original stone, one on the newly formed interior surface. The combination of internal wall insulation and heated panels were then monitored over a season to analyse their performance in use. Temperature and humidity sensors from 'Tinkerforge' were mounted on the surface of the wall inside and outside, but also at two locations between the hemp-lime and the stonework inside the refurbished wall. The data from these sensors was read at 5 minute intervals by a script running on the Pi and written to a csv file, which could then be transferred via wifi using the home owner's router, and analysed in open office. When the router was changed, the home owner was able to restart the monitoring without difficulty. The system ran reliably, and the data provided valuable information on how the hemp lime enhanced the thermal performance of the wall, while still allowing it to breath.

An ongoing project with the same colleagues is now exploring how, at low cost, users can be actively engaged via their smart phones. An open source project 'aircasting.org', launched in New York, has developed schematics and an app to engage schools and other community groups in mapping local pollution and by inference well-being. They provide an android app to collate and upload data from mobile phone sensors, including heart rate (an indicator of stress or wellbeing). Their 'aircasting' app uses sensors on the smartphone to measure noise levels, which may be extended to use other built-in sensors such as light levels. The app uses 'Bluetooth' to read, map and graph real-time data from external portable 'Arduino' based sensors for humidity, temperature and particulate levels. The external sensor device can be extended to add other sensors. The smartphone is then used to upload recorded data to the web, and display 'pollution' hot spots on digital mapping. This approach will shortly be used to engage secondary school pupils in Wales in evaluating their own environments, which will further inform studies on the effect of physical environment on well-being and learning. A recent EPSRC funded research project led by Salford University (Barrett et al, 2015) studied the effect of the classroom environment on primary school children in 150 Classrooms in 30 UK schools. This study demonstrated a 16% variance in learning progress over an academic year attributable to differences in the physical environment of classrooms.

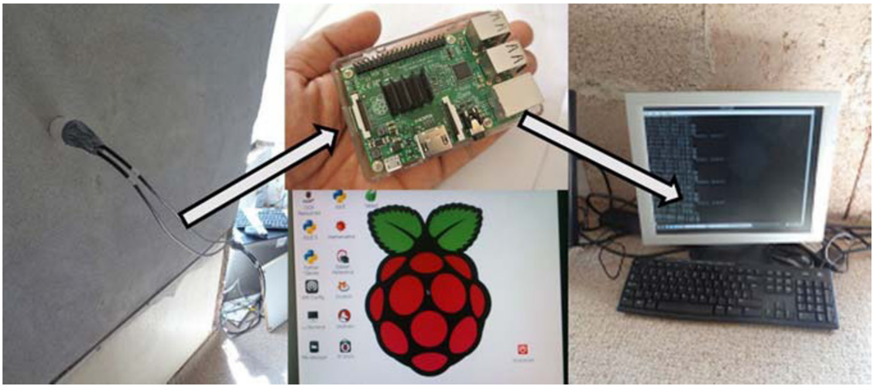

Fig. 2. The low cost sensor approach (a) sensors within wall. (b) Raspberry Pi. (c) displaying real-time data, optional screen, keyboard

8 The relevance of 'Living Labs'

In Europe, "Living Labs" use new and emerging technologies to involve participants in their 'everyday habitat' rather than to attempt to recreate that habitat in a lab, (founded on previous studies relating 'ambient intelligence' to cities and urban life). Nokia and others in the Intelcities FP6 research project set up the first EU network of Living Labs. They recognized the importance of actively engaging users in both exploration of their needs and desires and in exploring the capacity of emerging technologies to meet these (WING 2009). They saw that mobile phones were already augmenting peoples' capabilities in unforeseen ways: greater sense of security for young women in public spaces to be always in virtual contact with a supportive friend; virtual socialization for the housebound; prosthetics for memory, for disability, and for aging. Later Nokia acknowledged that their initial approach was "too corporate and projects should aim to be user-driven"(Niitamo, V 2007). Hirvikoski (2016) claims that now "Living Labs operate as intermediaries among cities, regions, firms, third sector and research organisations as well as citizens for joint value co-creation, rapid prototyping or validation to scale up and speed up innovation". It has become an accepted participatory research methodology, [it has also been termed an environment and a system (Bergvall-Kåreborn&Ståhlbröst)].Hirvikoski (op.cit) goes on to particularly describe the close relationship between living labs and the development stages of emerging smart cities. Bergvall-Kåreborn&Ståhlbröst(op.cit) set out the key role of a living lab as "to engage and empower users to participate in the generation of valuable and sustainable assets towards objectives set-up by its partners and customers". ENoLL (2016) have since refined this key definition, and now claim that to be a living lab five key elements must be present: "**active user involvement** (i.e. empowering end users to thoroughly impact the innovation process); **real-life setting** (i.e. testing and experimenting with new artefacts "in the wild"); **multi-stakeholder participation** (i.e. the involvement of technology providers, service providers, relevant institutional actors, professional or residential end users); **a multi-method approach** (i.e. the combination of methods and tools originating from a.o. ethnography, psychology, sociology, strategic management, engineering); **co-creation** (i.e. iterations of design cycles with different sets of stakeholders)."

9 Conclusion

"Smart city solutions must start with the city not the smart" (Schaffers et al 2011). Similarly, engagement must start with the needs of the participants, not the data. It is not yet clear to what extent and in what circumstances users can or will effectively engage in conservation and management, what tools will be sufficiently barrier free and easy to use, how their experience of heritage buildings can be enriched, nor what if anything makes a smart heritage building different from a smart building in general. For example, smart cultural heritage buildings such as museums involve some aspect of either tutelage or 'edutainment', perhaps more so than other smart buildings, but is that all? It is probable that in the future we are likely to have (too much) automated data, and we need easy to deploy and use mechanisms for filtering and analysing it, so people can make sensible decisions about heritage, and responses later be automated. Currently that data is collated by experts, making perhaps too many assumptions based on too little building centric data, let alone person centric information. What form will heritage information take when it is substantially crowd-sourced? These understandings are best achieved via Living Lab approaches. In the longer term the sustainable transformation of heritage buildings and landscapes into Smart Heritage can be held to be a key component in the metamorphosis of existing cities into Smart Cities.

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Using SITES for Sustainable Rehabilitation of Cultural Heritage Landscape Areas; Case of Giza Zoo

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Abstract. Green rating systems act as tools to support the decision making process for sustainable plans and actions. They provide guidelines and assessment methods to achieve sustainable performance along projects' lifecycle. This study investigates the application of SITES rating system to draw sustainable rehabilitation plans for Giza Zoo, which is considered one of the oldest and largest public parks in the Middle East. This comes as a response to the initiative of the Egyptian foreign alliance to rehabilitate Giza Zoo. The result of the study draws three scenarios for sustainable rehabilitation plans according to SITES checklist; in case of obtaining maximum, minimum and average points. Comparing between those three scenarios presents a preliminary assessment for the sustainable rehabilitation plan for Giza Zoo. This is developed to draw a preliminary project management framework incorporating sustainable rehabilitation practices along the project life cycle.

Keywords: Cultural heritage landscape; Decision making support tool; Giza zoo; SITES initiative; Sustainable rehabilitation management framework

1 Green initiatives for sustainable preservation

Cultural heritage landscape areas have rich collection of flora and fauna in addition to heritage buildings with particular architectural style. Yet, some of these areas suffer deterioration, which calls for immediate action to draw careful rehabilitation scenarios for cultural heritage assessment, preservation and management. Hence, there are active initiatives for incorporating the goals of sustainability and preservation. This can be traced through a series of workshops, papers and reports. This includes; Sustaining the Historic Environment in 1997, The Historic Environment: A Force for Our Future in 2001, the heritage office of New South Wales in Australia in 2004, The Sustainable Preservation Committee in 2004, followed by a workshop in Halfax, in 2005 and another workshop on "Greenbuild & LEED for Historic Building" in 2006, the National Trust for Historic Preservation Sustainability in 2007, the Pocantico

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Proclamation symposium in the APTI annual conference in Montreal 2008, and later, the European research project “Sustainable development of Urban historical areas through an active Integration within Towns” (S.U.I.T.) (Ross & Powter 2005). These initiatives pinpoint the socio-cultural benefit to protect the diversity of cultures, and create vibrant places that are socially and culturally connected and responsible to their community’s needs. This also includes the economic benefit through job creation, national economy stabilization and downtown revitalization. Moreover, the environmental benefit aims at fostering an attitude of environmental stewardship which is maximized by using Life cycle assessment to assess the durability and environmental performance of materials, products, systems and services along its life cycle (Ross and Powter, 2008; Rypkema, 2003).

2 Relevant codes, standards and rating systems

Many countries have developed national initiatives responsible for developing green rating systems. These are intended to help practitioners and decision makers consider the environmental impact along different project phases. They help define and set sustainability performance targets, measurement criteria, and verification of post project performance. Examples of such initiatives are; BREEAM in 1990, LEED in 1998 (IFMA, 2010), GB Tool, and the International Green Construction Code (IgCC) in 2010 (National Institute of Building Sciences, 2015). This is in addition to the Secretary of the Interior's Standards for the Treatment of Historic Properties, Cultural Landscapes, and Archeology and Historic Preservation. Certifications obtained from such rating systems are now considered projects' requirements because they represent third party verification of environmental stewardship for different project types and scales. Yet, it is noted that International Green rating systems that address parks and landscape are few in number, and even fewer number discusses hot arid climates. A Global Survey of Urban Sustainability Rating Tools (2014) identifies the current assessment tools worldwide. It shows that there are three available assessment tools for landscape and parks, these are; Cooperative Sanctuary in US and available internationally, Green Mark for Existing Parks; for New parks in Singapore, and Sustainable SITES Initiative (SITES) in US.

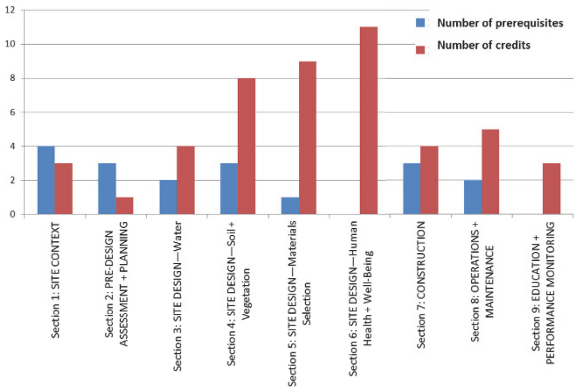

Fig. 1: The distribution of the number of prerequisites and credits among various sections of SITES V2 rating system

Sustainable SITES Initiative version-2 provides publicly available reference guide, rating system and scorecard for developing sustainable landscapes. It has a total number of 200 points distributed among nine main sections. It is constituted of 18 prerequisites (P: obligatory criteria with no assigned weighting) and 48 credits (C: optional criteria with assigned weighting). It has four levels of certification; Certified, Silver, Gold and Platinum. Project team members should achieve all prerequisites and a minimum number of 70 points to qualify for certification. It is shown from (Fig. 1) that the number of prerequisites and credits differ from one section to another. The maximum number of prerequisites is required to satisfy section 1: 'Site context', while there are no prerequisites for section 6:'Site Design-Human Health+ WellBeing', nor section 9: 'Education+ Performance monitoring'. Section 5: 'Site Design- Materials Selection has the greatest available points, followed by section 4: 'Site Design-Soil + Vegetation', and finally section 6: 'Site Design-Human Health + Well-Being'. It is also worth noting that SITES rating system provides checklist, but there is no defined methodology as to how to integrate the requirements into the sustainable rehabilitation process. This is why the study intends to present means of using SITES checklist as a base for decision making process through presenting a decision making framework for sustainable landscape rehabilitation activities.

3 Study area

Giza Zoo was first established to be a botanical garden, and then it expanded taking 50.4 feddans near the west bank of the Nile, with a rich collection of wild fauna and exotic flora from India, Central Africa and South America. This is in addition to architectural heritage landmarks including above all the suspended bridge designed and built by Gustave Eiffel, the Lion House (1901), a Lagoon in the center of the zoo, Japanese Kiosk (1924), five gates with sculptural motifs and particular arabesque and roman mosaic pebbles' footpaths. In 1870, it was passed under the state's responsibility; and currently it is put under the supervision of the Ministry of Agriculture in Egypt. By the mid-20th century, it was widely acclaimed as one of the best zoos in the world. Yet, in the last 30 years, it has been suffering bad management and short financial funding. Its area has been reduced by the trespassing of Cairo University on its western corner in the 1950-60s. Eventually, it was excluded from the International Federation of Zoos due to its deteriorated condition. Yet, the zoo still draws more than six million visitors annually (Raafat, 1997; Cairobserver, 1891). Recently, an initial protocol is signed between a number of international companies and the Ministry of Agriculture to rehabilitate Giza Zoo. The proposal includes reports with environmental studies and a proposed management plan (Dailynewsegypt, 2016). This calls for conducting this study to point out the importance of following a sustainable rehabilitation process for such a historical zoo.

4 Research Method

The study undertakes the following steps; data gathering, data analysis and evaluation of alternatives. It uses the scoring of SITES's checklist to provide guidelines and assessment methods for sustainable design, construction, and operation and management practices. It also acts as an indicator of the sustainability of the rehabilitation plans. This is developed to draw a project management framework incorporating sustainable rehabilitation practices. The research map is shown below in (Fig. 2).

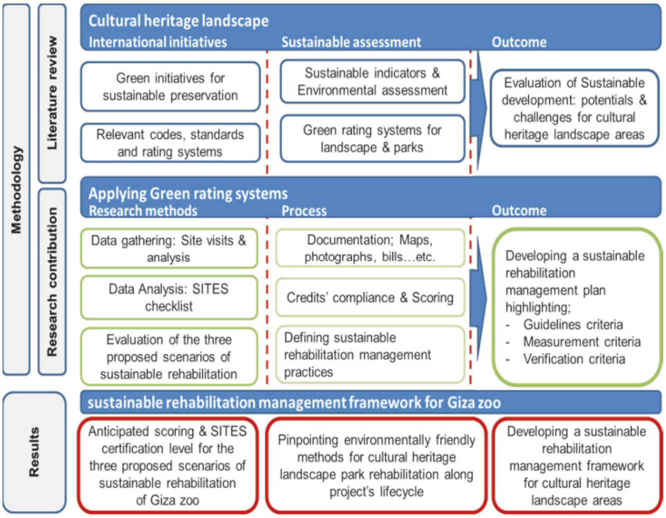

Fig. 2: Research method

3.1. Data gathering; the study starts with conducting site visits to gather the required data in order to comply with SITES prerequisites and credits. It prepares maps and photographs for the existing site location's potentials and constrains, existing flora and fauna, soil type, hardscape materials and elements, as well as the type and efficiency of the irrigation system.

3.2. Data analysis using SITES checklist; the study presents a preliminary assessment using SITES score rating for three proposed rehabilitation plans for Giza Zoo. It presents preliminary templates which practitioners should develop at early stages to guide them through sustainable rehabilitation management plan. Each prerequisite and credit is studied, documented and weighted unless there are; No Available Data (NAD) stated. Prerequisites and credits are distributed along different project phases; preliminary design (PD), design development (DD), construction (CO), and operation and maintenance (O&M) to enable drawing an eventual project management framework as shown in Table (1) which shows different activities along different project phases.

Section 1: 'Site Context': The site satisfies all first three prerequisites following the first compliance path. Additional sustainable practices are required during preliminary stages, e.g. site assessment survey that aims at identifying threatened / endangered flora and fauna, existing degraded sites, existing developed areas and finally conducting site accessibility and transportation study. Required documentation includes surveys and maps. It is noted that C1.5 and C1.6 are not clear whether or not they may be applied for existing sites.

Section 2: 'Pre-Design Assessment+ Planning': prerequisites have multiple synergies with sections (1), (4) and (8). It should be noted that in the case of Giza Zoo, flora and fauna have developed themselves into particular ecosystem that should be studied from a systemic approach. The rehabilitation plan should follow an Integrative design and front loading project management with a Bottom-up approach for community development that considers socio-cultural aspects. This can be done through interviews, questionnaires, seminars and workshops to investigate users' expectations and investors' interest to plan for short term and long term sustainability goals. It is noted that credits state the intent but require additional effort from practitioners to clarify the type of required engagement and desired outcome in a defined framework with measurable parameters and time frame.

Section 3: 'Site Design- Water': This section is probably the most challenging to achieve inspite of the fact that credits are considered synergistic. This is due to the poor efficiency of manual irrigation system applied on site, which calls for the urgent need of installing new efficient irrigation system integrated with onsite water recycling system. Financial support and qualified expertise are required to carry the required calculation of the proposed and baseline case for water savings, discharge volume and rate, and treated precipitation volume. Yet, it should be noted that C3.5 and C3.6 are not applicable for the project.

Section 4: 'Site Design- Soil+ Vegetation': It has a variety of sustainable landscaping practices that discuss soil, vegetation, biomass, urban heat island effect, and landscape vulnerability to wildfire. It is noteworthy that the language used for some credits concerns open landscape areas and new parks, hence it is difficult to apply them for this historical zoo. Also, the project cannot satisfy C4.10 because there are no on site regularly occupied buildings.

Section 5: 'Site Design- Materials Selection': it has few synergies; hence, most of the credits are considered direct guidelines for sustainable material selection, and suitability of restoration techniques to the nature of the project and context. Some credits are directly related to the rehabilitation practices of an existing landscape area, such as C5.2 and C5.4. Yet, some difficulties exist for searching, identifying and documenting sustainable material extraction and manufacturing practices, and sustainable material content; including wood origin, post-consumer and pre-consumer recycled content materials, regional material content, as well as material chemistry and hazards.

Section 6: 'Site Design- Human Health+ Well-Being': the project may earn numerous possible points under this section owing to its role as a social and cultural heritage landscape area. This is in addition to planning for more user group service and engagement. This can be done through new suggested activities that promote physical activity, social connection and mental restoration. Developing landscape elements is also required, this includes; studying entrances, gateways, landmarks, view lines, signage and shaded seating areas. Also proper planning and zoning is required to reduce the exposure to environmental tobacco smoke without affecting users' stay period, provide efficient and safe artificial lighting system, and promote sustainable means of site accessibility, parking and transportation. Moreover, the rehabilitation plan shall aim at creating social and economic benefit for local economy through hiring local workforce and support local businesses. On the other hand, the project fails to comply with C6.7 because it is not possible to alter the existing planting species.

Section 7: 'Construction': it requires identifying designated personnel, holding meetings, and assigning roles and responsibilities to apply sustainable construction practices. It is noteworthy that requirements of Pre7.3 and C7.4 apply only to disturbed areas subject to re-vegetation, C7.5: apply only to sites with construction and/or demolition activities, C7.6 requirements apply only to sites with waste disposal, and requirements of C7.7 apply to all diesel engines used on site during construction. Hence, credits' compliance shall be determined according to the detailed rehabilitation plan.

Section 8: 'Operations+ Maintenance': it requires developing a site maintenance plan that discusses; water, energy, soil, vegetation, as well as management of materials and sensitive site features. It provides a process for revaluation on an annual basis to adapt to future conditions and unforeseen changes, and this is considered a success key for the rehabilitation of this historical zoo. It also includes a specific section for maintaining the integrity of cultural landscape, including; any required repair or replacement of features, and how any conflict between historic and environmental objectives may be resolved.

Other recommendations require conducting a waste stream study to recycle organic matter and generate compost and mulch, this includes; vegetation trimmings, as well as food and animal waste. This requires estimating the amount of recyclable materials; allocate a space, system and service for storage, collection and onsite categorization of recyclables through a local recycling program. It also recommends applying best management practices for maintaining plant health while reducing the use of pesticides and fertilizers. Finally, the park can comply with C8.7 through option (3) due to the fact that manual maintenance is performed.

Section 9: 'Education+ Performance Monitoring': the requirements are flexible according to the nature of the project and users' groups. It requires promoting sustainability awareness and education that positively influence users' behavior. This aims at coupling comprehensive understanding of sustainable aspects within a cultural heritage framework as well as developing and communicating a case study. It also requires planning to monitor and report site performance and document at least three sustainable design practices to evaluate their performance- by an independent peer review.

Table 1: Project scoring using SITES checklist

	Available points	Maximum obtained points	Average obtained	Minimum Obtained points	Project stage
Section 1: SITE CONTEXT					
Pre 1.1: Limit development on farmland	Required				PD
Pre 1.2: Protect floodplain functions	Required				PD, O+M
Pre 1.3: Conserve aquatic ecosystems	Required				PD, O+M
Pre 1.4: Conserve habitats for threatened and endangered species	Required				PD, O+M
C1.5: Redevelop degraded sites	(3 – 6 points)	6	3	0	PD
C1.6: Locate projects within existing developed areas	(4 points)	4	4	0	PD
C1.7: Connect to multi-modal transit networks	(2 – 3 points)	3	2	3	PD
Total points for section 1	**13**	**13**	**9**	**3**	
Section 2: PRE-DESIGN ASSESSMENT + PLANNING					
Pre 2.1: Use an integrative design process	Required				PD,DD,CO O+M
Pre 2.2: Conduct a pre-design site assessment	Required				PD
Pre 2.3: Designate and communicate Vegetation and Soil Protection Zones	Required				PD, O+M
C 2.4: Engage users and stakeholders	(3 points)	3	3	3	PD & DD
Total points for section 2	**3**	**3**	**3**	**3**	
Section 3: SITE DESIGN—Water					
Pre 3.1: Manage precipitation on site	Required				DD & O+M
Pre 3.2: Reduce water use for landscape irrigation	Required				DD & O+M
C 3.3: Manage precipitation beyond baseline	(4 – 6 points)	6	4	0	DD & O+M
C 3.4: Reduce outdoor water use	(4 – 6 points)	6	4	0	DD & O+M
C 3.5: Design functional stormwater features as amenities	(4 – 5 points)	0	0	0	PD & DD
C 3.6: Restore aquatic ecosystems, synergies with P2.2 and P8.1	(4 – 6 points)	0	0	0	DD, CO & O+M
Total points for section 3	**23**	**12**	**8**	**0**	
Section 4: SITE DESIGN—Soil + Vegetation					
Pre4.1: Create and communicate a soil management plan	Required				DD, CO
Pre4.2: Control and manage invasive plants	Required				DD, CO, O+M
Pre4.3: Use appropriate plants	Required				DD, CO
C 4.4: Conserve healthy soils and appropriate vegetation	(4 – 6 points)	6	4	4	O+M
C 4.5: Conserve special status vegetation	(4 points)	4	4	4	O+M
C 4.6: Conserve and use native plants	(3 – 6 points)	6	3	3	O+M
C 4.7: Conserve and restore native plant communities	(4 – 6 points)	6	4	4	O+M
C 4.8: Optimize biomass	(1 – 6 points)	6	1	0	DD, O+M
C 4.9: Reduce urban heat island effects	(4 points)	4	4	0	DD
C 4.10: Use vegetation to minimize building energy use	(1 – 4 points)	0	0	0	DD, CO

C 4.11: Reduce the risk of catastrophic wildfire	(4 points)	4	4	4	DD, O+M
Total points for section 4	**40**	**36**	**24**	**19**	
Section 5: SITE DESIGN—Materials Selection					
Pre 5.1: Eliminate the use of wood from threatened tree species	Required				DD, CO
C 5.2: Maintain on-site structures and paving	(2 – 4 points)	4	2	2	DD, CO
C 5.3: Design for adaptability and disassembly	(3 – 4 points)	0	0	0	DD, CO
C 5.4: Reuse salvaged materials and plants	(3 – 4 points)	3	3	3	DD, CO
C 5.5: Use recycled content materials	(3 – 4 points)	3	3	0	DD, CO
C 5.6: Use regional materials	(3 – 5 points)	3	3	0	DD, CO
C 5.7: Support responsible extraction of raw materials	(1 – 5 points)	1	1	0	DD, CO
C 5.8: Support transparency and safer chemistry	(1 – 5 points)	1	0	0	DD, CO
C 5.9: Support sustainability in materials manufacturing	(1 – 5 points)	1	0	0	DD, CO
C 5.10: Support sustainability in plant production	(1 – 5 points)	1	1	1	DD, CO
Total points for section 5	**41**	**17**	**13**	**6**	
Section 6: SITE DESIGN—Human Health + Well-Being					
C 6.1: Protect and maintain cultural and historic places	(2 – 3 points)	3	2	2	O+M
C 6.2: Provide optimum site accessibility, safety, and wayfinding	(2 points)	2	2	2	O+M
C 6.3: Promote equitable site use	(2 points)	2	2	2	O+M
C 6.4: Support mental restoration	(2 points)	2	2	2	O+M
C 6.5: Support physical activity	(2 points)	2	0	0	O+M
C 6.6: Support social connection	(2 points)	2	2	2	O+M
C 6.7: Provide on-site food production	(3 – 4 points)	0	0	0	PD, O+M
C 6.8: Reduce light pollution	(4 points)	4	4	0	DD, O+M
C 6.9: Encourage fuel efficient and multi-modal transportation	(4 points)	4	4	4	DD, O+M
C 6.10: Minimize exposure to environmental tobacco smoke	(1 – 2 points)	2	1	0	O+M
C 6.11: Support local economy	(3 points)	3	3	3	O+M
Total points for section 6	**30**	**26**	**22**	**17**	
Section 7: CONSTRUCTION					
Pre 7.1: Communicate and verify sustainable construction practices	(Required)				CO
Pre 7.2: Control and retain construction pollutants	(Required)				CO
Pre 7.3: Restore soils disturbed during construction	(Required)				CO

Pre 7.4: Restore soils disturbed by previous development	(3 – 5 points)	5	3	3	CO
Pre 7.5: Divert construction and demolition materials from disposal	(3 – 4 points)	4	3	3	CO
C 7.6: Divert reusable vegetation, rocks, and soil from disposal	(3 – 4 points)	4	3	3	CO
C 7.7: Protect air quality during construction	(2 – 4 points)	2	0	0	CO
Total points for section 7	**17**	**15**	**9**	**9**	
Section 8: OPERATIONS + MAINTENANCE					
Pre 8.1: Plan for sustainable site maintenance	(Required)				O+M
Pre 8.2: Provide for storage and collection of recyclables	(Required)				O+M
C 8.3: Recycle organic matter	(3 – 5 points)	0	0	0	O+M
C 8.4: Minimize pesticide and fertilizer use	(4 – 5 points)	4	4	0	O+M
C 8.5: Reduce outdoor energy consumption	(2 – 4 points)	2	2	0	O+M
C 8.6: Use renewable sources for landscape electricity needs	(3 – 4 points)	3	0	0	O+M
C 8.7: Protect air quality during landscape maintenance	(2 – 4 points)	4	2	2	O+M
Total points for section 8	**22**	**13**	**8**	**2**	
Section 9: EDUCATION + PERFORMANCE MONITORING					
C 9.1: Promote sustainability awareness and education	(3 – 4 points)	4	4	4	O+M
C 9.2: Develop and communicate a case study	(3 points)	3	3	3	O+M
C 9.3: Plan to monitor and report site performance	(4 points)	4	4	4	O+M
Total points for section 9	**11**	**11**	**11**	**11**	

5 Results & discussions

The result of the study draws three scenarios for sustainable rehabilitation plans of Giza Zoo. Scenario (1) suggests complying with the minimum number of points with the tightest budget limitation. Surprisingly, it is found that the rehabilitation project can still earn the certification with 70 possible points. This indicates that the project shall be eligible for the SITES certification within the conventional framework of sustainable

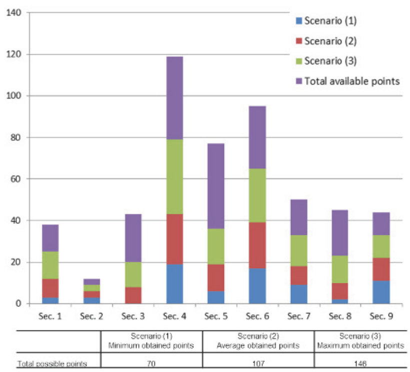

Fig. 3: Comparing the three proposed sustainable rehabilitation scenarios

rehabilitation. The bar was raised in the second scenario, adding more sustainable requirements that qualify the project for 107 possible points within an average budget. This qualifies the project for the Gold certification level. Finally, Scenario (3) suggests obtaining maximum scoring of 146 possible points. The project shall qualify for the Platinum certificate; hence, it shall benefit from many incentives and presents a case study with many lessons to be learnt. Figure (3) shows that it is possible to obtain all points under section (2) and (9) for all proposed scenarios. Section (4) represents the greatest gap between the total possible points and the maximum points' scenario. This suggests that there are constrains to earn points under this section and that credits' requirements do not consider the case of existing landscape areas with cultural heritage values. It is also noted that the minimum points' scenario was not able to earn points under section (3) at all. This indicates that achieving water efficiency with the existing status quo of the zoo requires additional effort and budget allocation.

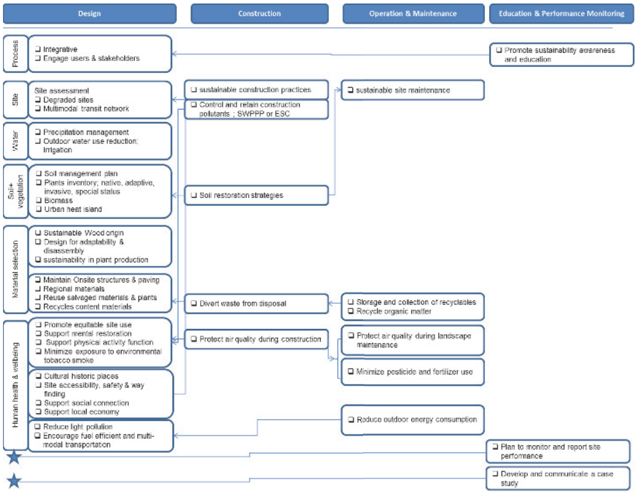

Fig. 4: Sustainable rehabilitation management framework for Giza Zoo based on SITES checklist

Eventually, this is developed to draw a management framework for sustainable rehabilitation activities for Giza Zoo as shown in (Fig. 4). They are distributed along different project phases and indicate synergies and tradeoffs.

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Between the Tangible & Intangible Smart Reading of Heritage Buildings

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Abstract. Information era have brought out several technologies that have added a lot into heritage buildings, starting from documentation technologies, virtual presentation technologies, in addition to various dissemination techniques and technologies that connect the public with heritage buildings and spaces. Never the less, HBIM technologies have provided more depth in dealing with heritage buildings in the scope of efficiency, retrofitting in addition to management. All the previous smart technologies have dealt with tangible aspect of heritage providing a physical reading for buildings and spaces. This paper deals with the results of the use of technology in recording and documenting archaeological heritage buildings and the extent of its success in its goals, including the reading of history through the building to check the logic of the argument of Ebn Rushed in his book 'The Incoherence of the Incoherence', where he argues that: " If one looks into a made of any manufactures without perceiving the wisdom behind such made and the purpose intended, and if it does not stand originally with such wisdom one might think it is possible that there are so made, which agreed in any form and any quantity agreed and put any agreed-volume and in whatever order." Such argument will be investigated through the analysis of a case study with a proposed methodology to assess the results of retrofitting heritage buildings with the consideration of intangible historical aspects rather than tangible physical aspects alone.

Keywords: tangible heritage; intangible heritage; building memory; hidden wisdom; smart reading

1 Introduction

In recent years, the generation of 3D cultural heritage models has become of great interest to the architectural world. The reason behind the facilitation of such occurrence is the wide spread of recent technologies such as laser scanning and photogrammetry that has enabled the recording and documentation of cultural heritage sites. Such technologies have made it possible to accurately read and document complex heritage structures from a distance which would have not been possible with previous survey methods. In addition, smart reading of heritage buildings has enabled the presentation, analysis and archival of heritage

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documentation. Moreover, not only has it helped in the smart documentation of heritage buildings, it also has become of major significance to the restoration of such buildings. According to Charter of Venice, "The goal of the restoration is to preserve the aesthetic value of the heritage object", (Charter of Venice, 1964). However, in order to be able to accomplish a successful conservation practice, one must fully understand the historical background and the cultural heritage of the object. Moreover, value has always been the fundamental of heritage conservation. This paper aims to assert as well as explain the importance of understanding the cultural heritage and value behind the structure in order to accomplish both tangible and intangible smart reading and proper assessment of the building.

2 Building Reading Methods

According to Marta de la Torre, when it comes to the assessment and analysis of heritage buildings, there are two main types of assessment necessary to insure a successful conservation practice: Physical Condition Assessment and Cultural Significance and Value Assessment (Torre, 2002). The two types of assessment represent both the tangible and the intangible reading of the building. The following diagram represents a new simplified version of Torre's planning process methodology necessary for the conservation process.

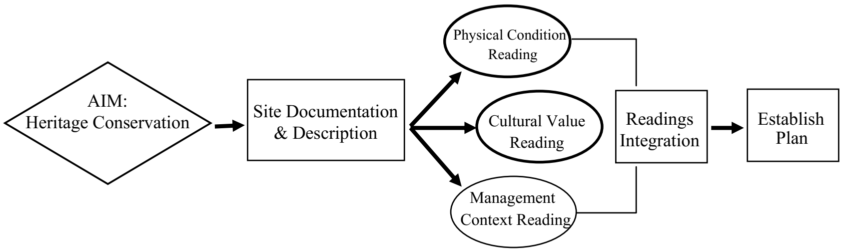

Figure 1 Heritage Conservation Planning Methodology

2.1 Physical Reading

Physical reading or assessment is crucial for the conservation practice where it involves heritage practitioners analyzing every physical aspect of the building in order to fully understand how to carry out the conservation process. Physical reading includes analyzing the current physical condition of the building, building materials, its construction system, the surrounding environment and natural factors, the building behavior, the external physical factors etc. All these physical aspects and more help form an accurate physical reading for the heritage building.

2.2 Heritage Value Reading

Heritage Value Assessment has become crucial in any heritage conservation practice since value strongly shapes the decisions that are made. The purpose of the heritage value assessment or evaluation is to understand the heritage significance of the subject building. One of the main drives of executing a Heritage Significance Evaluation is not to evade the heritage value of the object but rather advocate its value through its conservation. There is no standard method explaining how heritage significance should be evaluated. It merely depends on the structure and procedures vary throughout the world. According to Hermann and Rodwell, there are many types of heritage values such as cultural, economic, political, aesthetical and more which makes it slightly difficult to carry out a heritage value assessment (Carsten Hermann, 2015). However, when it comes to assessing heritage significance, cultural values are considered to be of outmost importance.

This following section will showcase a case study example where heritage value assessment (intangible smart reading) was a key factor in the success of a conservation process alongside the physical assessment.

3 Case Study

3.1 Case Study Introduction

The case study comprises the restoration of the Ahmed Ibn Tulun Mosque Minaret. Minarets are one of the most important elements in Islamic Architecture that are worthy of studying and analysing their contained building, art and decoration technique. In addition to being a wonderful record of all phases experienced by Islamic Architecture in Egypt, manufacturers competed and excelled in the refinement and development of its forms making the minaret of the Ibn Tulun a unique model between the Egyptian minarets. The Mosque is located in Cairo, Egypt and it is considered one of the oldest mosques in the city surviving in its original form. In addition, it is the largest mosque in Cairo in terms of land area.

3.2 Physical Reading

All physical data and analysis concerning the minaret were collected and documented in order to set a proper plan for the restoration process. Including physical measurement data where it was found that the dimensions of the minaret where in violation with the Nile Scale (54.05 cm) used in the construction of the mosque during a documentary of the minaret in 1993. Moreover, after the 1992 earthquake the minaret underwent a thorough examination where the internal examination showed that there is disintegration in the stones and breadth in the vertical seams, in addition some mortar was missing as two column hulls were displaced. Moreover, the external examination showed that the upper parts of two opposite columns (hull) of the upper floor were shifted 5cm to the outside in addition to deterioration of the stones in the western direction and erosion in the southwest.

Figure 2 The effect of the 1992 earthquake

Furthermore, each climatic factor was analysed in terms of its effect on the physical condition of the minaret. This analysis showed that sunrays caused deterioration in the north-west, west and southwest facades. As for the temperature, it showed that the use of stone with different thicknesses and different grading provides protection even to the parts of smaller thickness through shade and shadows, thus increasing air movement because of difference in temperature. In addition, wind analysis showed that the difference in temperatures creates a difference in pressure causing air to move more efficiently as seen in figure 3. The direction, speed and intensity were monitored through wind movements in Cairo. Ventilation and its impact on the design of the openings were also analysed.

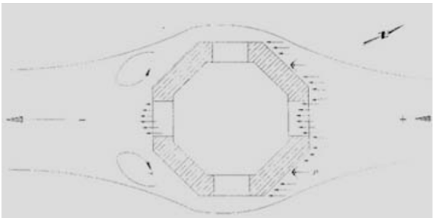

Figure 3 Wind movement in space surrounding minaret

Structural assessment of the minaret was also carried out and it included studying the balance and behavior of the minaret under the influence of static loads. The aim was to figure out a way to transfer those stresses as well as the distribution of loads and moments through structural elements, so that the restoration process can be carried out in an appropriate manner and allocate the elements of importance to transfer load.

After carrying out the physical assessment of the minaret and analyzing every physical aspect exits, it was of outmost importance to understand the history and the historical value behind the minaret in order to carry out a proper restoration process that would preserve the original value of the minaret if not add to it.

3.3 Historical Value Reading

After conducting the physical assessment, it was important to understand the historical value of the minaret and fully comprehend the history behind its construction. After doing that it was understood that the architect had originally planned for the hulls of the columns on the east and west to be in two parts, thus determining the key movements and impact of the horizontal forces arising from the quake at those two locations. Therefore, it has to absorb most of the horizontal impact forces in the form of kinetic energy, not stresses and thus to maintain the equilibrium of the minaret in the new situation and to reduce the impact on the rest of the columns. Moreover, noticing the use of wooden beams on the upper part of the minaret shear frames, which led to reduced conformation horizontal incident at the top of the minaret. As a result, the hull minaret moves from high callus flexibility to stability. In addition, through the structural analysis of the manner of distribution of loads, Palmiznh found that the structural elements sectors were quite enough to withstand the stresses, therefore the re-construction of the minaret can continue and it was found that it was the best method of restoration. This process assessment was fundamental to study the importance and uniqueness of the minaret and to stress the genius of architecture in the Islamic period in addition to realizing the influence of the Muslim architecture on the dynamic loads of the wind and earthquakes.

Only when the historical value of the minaret was understood alongside analyzing its physical condition that, the restoration team was able to generate a proper and appropriate planning process for the minaret restoration where every aspect was taken into consideration to ensure a successful restoration.

3.4 Reading Integration outcome

When information gathered from the different assessments the restoration team was able to produce an outcome that would help shape the planning for the restoration. This outcome is as follows. The minaret was subjected to an earthquake in October1992, followed by another one in November 1993 and did not fall or collapse, which shows how equilibrium static force is stable in the minaret. When columns where shifted to the outside, the loads moved and where distributed to neighboring parts. However, Brazier was still out of equilibrium so there was no need for a solid purpose to lift the burden as much there was a need to follow the installation process accurately in order to require the work of a scaffold. In addition, there was a solid threshold for openings on the lower level because the openings weakens the wall and attracts cracks. Finally, the aim of the work done to the displaced parts is to take the vertical load in addition to avoiding any defect and fall of stones during restoration.

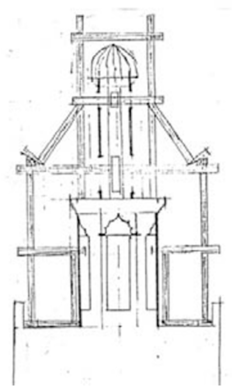

Figure 4 Suggested Scaffold

4 Conclusion

In conclusion, recent technologies such as laser scanning and more, has helped a great deal in the preservation of our herit/age and has enabled us to digitally document heritage buildings. However, smart reading of a heritage building does not only include tangible assessment and digital documentation, one must also assess the significance of the building by understanding its cultural and historical value; the intangible smart reading. One might say that the only thing smart in the smart reading of a building is being able to relive its history and learn from it. As seen in the showcased case study, only when tangible and intangible smart reading combine, does the conservation practice ensured to be successful.

Acknowledgements

This research would have not been without the effort of Sanaa Abd El Maksud who was responsible for the restoration of the Ibn Tulun Mosque minaret where she provided all the information and details required for the case study. In addition, much appreciation to Esraa Abdelhady who assisted a great deal in the completion of this research paper.

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Radicalism vs. Consistency: The Cyber Influence on Individuals' Non-Routine Uses in Public Spaces, the case of Cairo.

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Abstract. Since the emergence of the concept of user-generated content websites – Web 2.0, Internet communications have developed as a powerful personal and social phenomenon. Many Internet applications have become partially or entirely related to the concept of social network; and cyberspace has become a space about 'us' not 'where' we are. This paper investigates the theoretical grounds of the effect of cyber experience on changing the individuals' uses of the public spaces, and sustaining this change through maintaining the ties and reciprocal influence between actions in physical and cyber spaces. It aims at examining the impact of cyber territories on the perception, definition and effectiveness of personal space within different circumstances; and its role in changing the uses of spaces where people used to act habitually. The personal space, here, will be represented as the core of both: change and consistency – the space of bridging the reciprocal effect of cyber and physical counterparts, which is transformed through the experience of physical events mediated into the cyberspace. The paper is part of a study which looks at the case of Tahrir Square during the Egyptian political movement in 2011. We will compare the activists' actions and practices in the Square during different events of non-routine use of the square and its surroundings. The case study will show the level of consistency in the features of the produced personal space within different waves of the revolutionary actions for all that different circumstances, motivations and results.

Keywords: Cyberspace; activist; personal space; political movements; public space.

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1 Introduction: The Cyber influence on Individuals' Practices in Physical Public Spaces

Since the emergence of the concept of user-generated content websites "Web 2.0"[1], the Internet has developed as a powerful personal and social phenomenon. Many Internet applications have become partially or entirely related to the concept of social network (Park 2009) and cyberspace has become a new home of the mind (Hunter 2003). The term *'space'* generally conceptualizes the ability to move, act, create and describe (Krippendorff 2010). Breaking the physical borders, Klaus Krippendorff (2010) argued that space is about 'us' not 'where' we are. 'It exists only for actors who recognize possibilities and act in them: changing the location of their bodies, interacting with one another, or creating new artefacts' (ibid). Cyberspace, here, is an example of this abstracted space. It is based on the communities of actors who exceed the physical boundaries through mediated communication.

The number of studies on cyber communities has significantly increased in five perspectives: social, business, development, application and methodology issues. According to its multidimensional approach, all five perspectives, especially the social perspective, appeared unable to produce a conclusive definition of cyber communities (Li 2004). The social perspective of virtual communities addresses the definitions into two main approaches. The first one is the sociological definition of Tönnies community of mind, where virtual communities are defined using the elements of bonding and culture (Etzioni & Etzioni 1999). According to Tönnies definition, there are three types of communities: (1) community by kinship, (2) community of locality and (3) community of mind. Virtual communities resemble a community of mind but through an electronic communication medium (Rothaermel and Sugiyima 2001). The second one considers virtual communities as the opposite concept of 'offline community of place' or proximal community (Scott et al. 2005), where the offline face-to-face interaction is converted into mediated one (Park 2009). Offline communities are defined as a group of people who share common ties and social interaction through an area physical space for a specific period of time (Hamman 2001, p.75)[2]; while virtual communities are *"mediated social spaces in the digital environment that allow groups to form and be sustained primarily through ongoing communication processes"* (Bagozzi and Dholakia, 2002, p. 3); or a group that shares thoughts or ideas, or works on common projects, through electronic communication only (Digital Future Project 2007).

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[1] It includes social networking sites, blogs, wikis, video sharing sites, hosted services, web applications, mashups and folksonomies. Source: Wikipedia.com

[2] Hamman, R. (2001) Computer Networks Linking Network Communities, Source: Al-Saggaf and Begg: Online Communities versus Offline Communities 2004

The motivations of participants in virtual communities include: daily-life needs (Bakardjieva 2003), online friendships (Coon 1998)[3] and the desire to obtain and exchange information (Ridings et al. 2002); but, mainly, the intention of participants is determined by the social identities of the individual (Bagozzi & Dholakia 2002). The theory of 'uses and gratification' is used to explain this argument. The theory hypothesizes that different consumers use the same media messages for different purposes, depending on their individual needs and goals (Sheldon 2007, p. 40[4]); and users meet their motivation within three main categories of virtual communities: Blogosphere, Wikis and social network sites. The world now faces new forms of association which are called social networks. It is a rich source with several dimensions, which mobilizes the flow of resources between countless individuals distributed according to variable patterns (da Costa 2005).

2 Literature Review: Virtual Communities V. Cyber Space

Based on different platforms, motivations and ways of interaction, Cyber communities represent the virtual version of the real counterpart. Coon (1998) was among the first to suggest that the virtual communities resemble real communities and that people can form communal relationship through computer-mediated communication on the Internet. [5] Therefore, involvement in virtual communities/ cyberspace leads to offline actions: in social activism, daily use, members' interactions, social links and posting information. Space and cyberspace are roughly equivalent, at least in the sense of sharing the four common notions of place, distance, size and route (Bryant 2001). These four items reflect: locating specific targets in cyberspace, time value and its relation to distance and size, and finally the description of the movement within the space. Terms like 'visiting' a web 'site', typing its 'Uniform Resource Locator' and 'entering' chat 'rooms' are indicators for this approach.

Places in cyberspace are, in fact, software constructions which create environments of interaction. These places (cyber objects) are dependent on cyberspace, while the opposite is untrue. Cyberspace can exist in the absence of all information; the potential to transmit does not disappear along with the information. Actually, cyberspace depends on human use of these potentials. It is not only a matter of investigating cyber objects within cyberspace, it is about the responsibility for creating and protecting those cyber objects and the space in which they exist. Without these ongoing human activities, cyberspace and cyber objects would become meaningless. Networks provide platforms for media resources to be shared among

3 Source: Li H. (2004)

4 Source: Katherine K. Roberts (2010) Privacy and Perceptions: How Facebook Advertising Affects its Users, *The Elon Journal of Undergraduate Research in Communications,* Vol. 1, No. 1, 24-34.

5 Source: Li H. (2004)

nodes, resulting in the flow of information – which activate cyberspace. Since then, a direct relationship is standing between existence and actions. For example, even users enter and leave cyberspace whenever they please, the point for users is not just to 'be there', as traditional meeting places, but to 'present' themselves and to interact with others.

Individuality, the effective factor in changing the concept of community, has its reflections on the cyberspace. Cyberspace has been divided. People hold rights of exclusion to a property, and millions of tiny land-holdings appeared (Hunter 2003). Taking into consideration the self-defining and self-regulated structure space, cyberspace "embodies the liberal democratic goals of individual liberty, popular sovereignty, and consent of the governed" (Hunter 2003). People hold the responsibility to define the space through their properties *(territories)*, shape it into networks and sub-networks, enhance it while contacting and, continuously, reshape it by eliminating people and posts.

Territory, also referred to as personal space, is defined as more distant, somewhat removed from the immediate person, and it involves use of places and objects in the environment (Daskala and Maghiros 2007). Although boundaries are not always very clear, people are aware of their existence and act accordingly. This starts with the territorial behaviour which is a boundary-regulation mechanism of: marking of a place or object, communication that it is owned, regulating interpersonal interaction and to achieve a desired level of privacy.

In the physical space, personal space is literally 'attached' to the self; and in the cyber milieu, personal territory is stands for the cyber personal space. It includes all the cyber personal data of the individual, as well as the online activities. According to Daskala et al. (2007), the use of the notion of territories and personal space may provide us with a better way to map out and conceive the personal space and the management of personal data and privacy in the cyberspace. Within this space, the individual controls all data and actively decides on who and what part to access.

The personal territory is shaped by a dynamic data-sphere (bubble), whose size varies according to its content, the type of interaction and the level of trust to the interaction milieu. This bubble set as the nucleus of a two-way interaction, where any taken action is applied to: the direction of the movement of data, the classification of the personal data (level of privacy) as well as time and spatial factors – either physically: personal or public device, or virtual: the type of used website. This bubble sets adaptable borders, which change according to its will of increasing or decreasing them, and represented by markers to convey the idea of ownership (for example: Log-in screens). The last dimension is the built up bridges which provide links between physical and cyber milieus.

Frequent logging into cyberspaces converts them to online stages for interaction, which affect the offline counterpart. Internet has increased the number of people to contact with; and as the related apps and devices are developed, the number of virtual communities' members who keep in contact with their cyber world increased steadily. While logged in, people post and receive information from their communities. This interaction is considered to have a positive impact on the world, according to the

Digital Future Project Reports, which shows an increase in the positive responses 2013-2015, even for those who do not use Internet.

Such participation affects the behavioral patterns within the physical spaces (offline communities), on one or more of the following dimensions:

Social activism: Participation in social causes through the Internet has increased, even for those who were not familiar with such activities (Digital Future Project Reports 2007).

Social links: a) cyberspace helps the users to find growing numbers of online friends, as well as friends they first met online and then met in person, 5 friends on average (Digital Future Project Reports 2015); b) cyberspace users show an increased regular stay in contact with online friends. This indicates a belief in the use of internet for maintaining social relationships 58%, with 62% specially using texting (of mobile phone users).

Daily life activities: a) Using mobile phones for functions other than talking has increased for a wide range of internet based actions: access the internet, send/receive pictures/video/messages, use apps, GPS mapping services, use social networking sites, watch/listen to streaming video/music, instant messages, personal digital assistant functions, download ringtones/music/mp3/videos and check into locations; b) Online purchasing for 78% of the adult internet users, who became more confident about their personal and security information while shopping online (Digital Future Project Reports 2015).

In parallel, political life was affected by the cyber experience. First of all, people almost trust in Internet. 43% of Internet users said that most or all of the information online is reliable. The percent increases to 74% when users talked about websites which they visit regularly, 76% of the information posted by governments and 69% of the information posted by established media (DFP 2015). On the other hand, information posted by individuals on social networking sites do not have the same reliability for users.

A small percentage of respondents said that governments should regulate the Internet, this real involvement in the cyberspace as a source of information has a significant impact on the political campaigns, knowledge and freedom to respond towards governments actions. In spite of that, in compatibility with Fox and Roberts (1999)[6] argument of the complementary relationship between virtual and real communities instead of completely replacing them, the majority still do not consider virtual communities as the only tool to gain political power.

This impact of cyber experience inspired examples of protesting around the world, as a means of public contribution in political life. Social media was the driving force behind the swift spread of revolution throughout the world during the last six years, as new protests appear in response to success stories shared from those taking place in other countries (Skinner 2011). Through social media, protestors create communities

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[6] Ibid.

* See: Skinner, J. (2011). "Social Media and Revolution"

to: organize their movements, share insights, news and support; and, finally, learn from the experience of others, which is essential for activists' success.

Significant examples are drawn around the Arab spring uprisings since 2011; in Tunisia, in response to oppressive regimes and a low standard of living, and in Egypt, the case of public participation affected by cyber-physical relationship. These cases reflected on the political movements in other countries of the region in several forms in Libya, Yemen, Bahrain and Syria; in addition to minor reflections in Algeria, Iraq, Jordan, Kuwait and Lebanon. Some spaces appeared as the physical spaces of these movements. Tahrir square of Cairo was the biggest example with successive waves of events. A smaller example was of Pearl Roundabout (Lulu Roundabout) in Manama-Bahrain. Inspired with the Arab spring (Skinner 2011), the Occupy movement instigated in USA[7] 2011; called together by groups like Adbusters and Anonymous. The online organized protesting was transferred into physical public spaces, which were occupied by protestors, of both Arab Spring and Occupy Movement. The longest period of continuous occupation, the Hong Kong version of Occupy Movement (15 October 2011 - 11 September 2012), as well as other examples all over the world, transferred the protesting into physical spaces. This has created reactions and impacts on social and political dimensions within their countries. These cyber-organized, physical-applied movements led to several impacts, such as regime change (Tunisia and Egypt), passing of various laws (Spain) and alerting some economic issues (USA).

In all cases, social media played a major role in motivating protestors. Hashtags converted the scattered tweets into public discussions; Facebook allowed people to express their support; Skype was used to hold conference calls with participants of different locations; and multi-media was used for documenting and publishing events. In conclusion, it was a tool to connect protestors and send their messages to the world. On the other side, governments also recognized the role of social media in such movements, since then took actions like shutting down specific sites, blocking Internet service, and accusing active users of unrelated crimes. In parallel, physical spaces of protesting were places of clashes between protestors and police, while trying to clear them even with force.

3 The Case Study Background

The Egyptian revolution that took place in *Tahrir* Square in 2011 continuous to provide evidence on the frequent movement of the activists between cyber spaces, like Facebook, blogs, twitter and YouTube, and the public spaces, like squares and streets. Facebook was elected as a space which was able to represent the physical counterpart. It was the main turning point which has transformed social communication in the history of social network sites (Roberts 2010). Facebook, the republic of 1.59 billion monthly active users (Facebook, December 2015) all around

[7] This movement which began in Manhattan to protest corporate greed as well as the performance of elected officials, encouraged protestors around the United States and then around the world.

the world, stands as the most popular and influential social networking website (Di Capua 2012) - in comparison with WhatsApp (500 million population), Twitter (284 million) and Instagram (200 million) (Source: CNBC) [8]. 1.04 billion People who log into Facebook every day spend 20 minutes in average per visit (Source: Infodocket), upload: 136,000 photos, update 293,000 statuses and post 510 comments every 60 seconds (Source: The Social Skinny). Statistically, it is vital and big enough to represent the community, with sufficient hours of interacting on a wide range of interests through a wide variety of verbal and non-verbal expressions: symbols, words, photos and videos.

Tahrir square stands for the most important public space in the Egyptian experience of the Arab spring. The square, originally named "Ismailia Square", was part of the political movements in Egypt and well connected to its revolutions since 1919 – when it was informally named "Tahrir Square" (Salama 2013) until officially being renamed in 1960. The square, then, became surrounded by several public and governmental buildings; such as: the Egyptian Museum, the House of Folklore, the National Democratic Party-NDP headquarters building, the Mogamma government building, the Headquarters of the Arab League building, the Nile Hotel, Kasr El Dobara Evangelical Church and the original downtown campus of the American University in Cairo. All these have converted the square to become a part of the concept of *melk el hokomoa* (property of government) which occupied the Egyptians' conception of public space for the following six decades. This notion started to change gradually since the 1970s, when socialists started to consider public spaces as places to protest against capitalism. The government contracted these actions through police surveillance. Therefore, the cyber alternative was established and got tied to the public spaces like Tahrir Square.

This paper is part of a study which aims to analyse the individuals' cyber and physical practices during political movements in public spaces, and through their personal spaces – the building unit of space. Through a case study analysis, the study attempts to provide evidence on the relationship between defining cyber and physical personal spaces, through users' inputs – whose communities represent the space.

The case study will be conducted in the city of Cairo, namely in Tahrir Square and its surroundings. A series of major events will be selected as key events of the political movement within the defined three years scope. The events are all non-routine acts which have made: a) a significant change in the actions took place in the selected public spaces and b) a direct impact on the community engagement in this movement and its results. Two events are considered turning points of regime change, while the others established for these changes. The selection criteria is that: a) the event is caused by a physical action which motivates the protestors b) the event took place in a public space which is geographically inside the selected case study and within the defined timeline, c) the event was mediated in the cyberspace, d) the event

[8] Source of statistics: https://zephoria.com/top-15-valuable-facebook-statistics/ and https://newsroom.fb.com/company-info/ . Last visit: 24/04/2016

has been initiated with collective effort; and finally e) had a significant impact on the political movement of the selected case (see figure 1).

The series of event starts with the death of Khalid Sa'eed under police custody. The memorial Facebook page "We are all Khaled Said" stands as a nucleus of change, which started online and moved to the streets of Cairo. Second is the major wave of Jan.25th which sparked with online demands to protest against the deterioration of political, economic and social conditions; as well as a reflection of Khaled Sa'eed death. The third event was under the rule of the Supreme Council of the Armed Forces when Mohammad Mahmoud Street hosted the protestors who moved to speed up the transfer of authority. This has resulted in changing the government team and announcing a timetable of the authority transfer. The fourth event took place in August 2012, following the state declaration of a new a constitutional to enhance its power, followed by the Rebellion movement; and finally, the turning point that took place in Tahrir Square in June 30th, 2013.

The selected events, within the three phases, display variety in the circumstances and motivations of actions; while the relationship between the cyber and physical spaces of engagement keeps constant. The activists' inputs – virtually and physically, will be tracked through documented writings, archives, newspapers and visual materials which are saved either as hardcopies, soft copies or on cyberspace. The sample and its aim of engagement will be the constants of the study, while the circumstances will vary upon the several parts of the analysed case. They, all, have an active social media account (Facebook, twitter etc.) and have participated in all selected events of the study as indicated above.

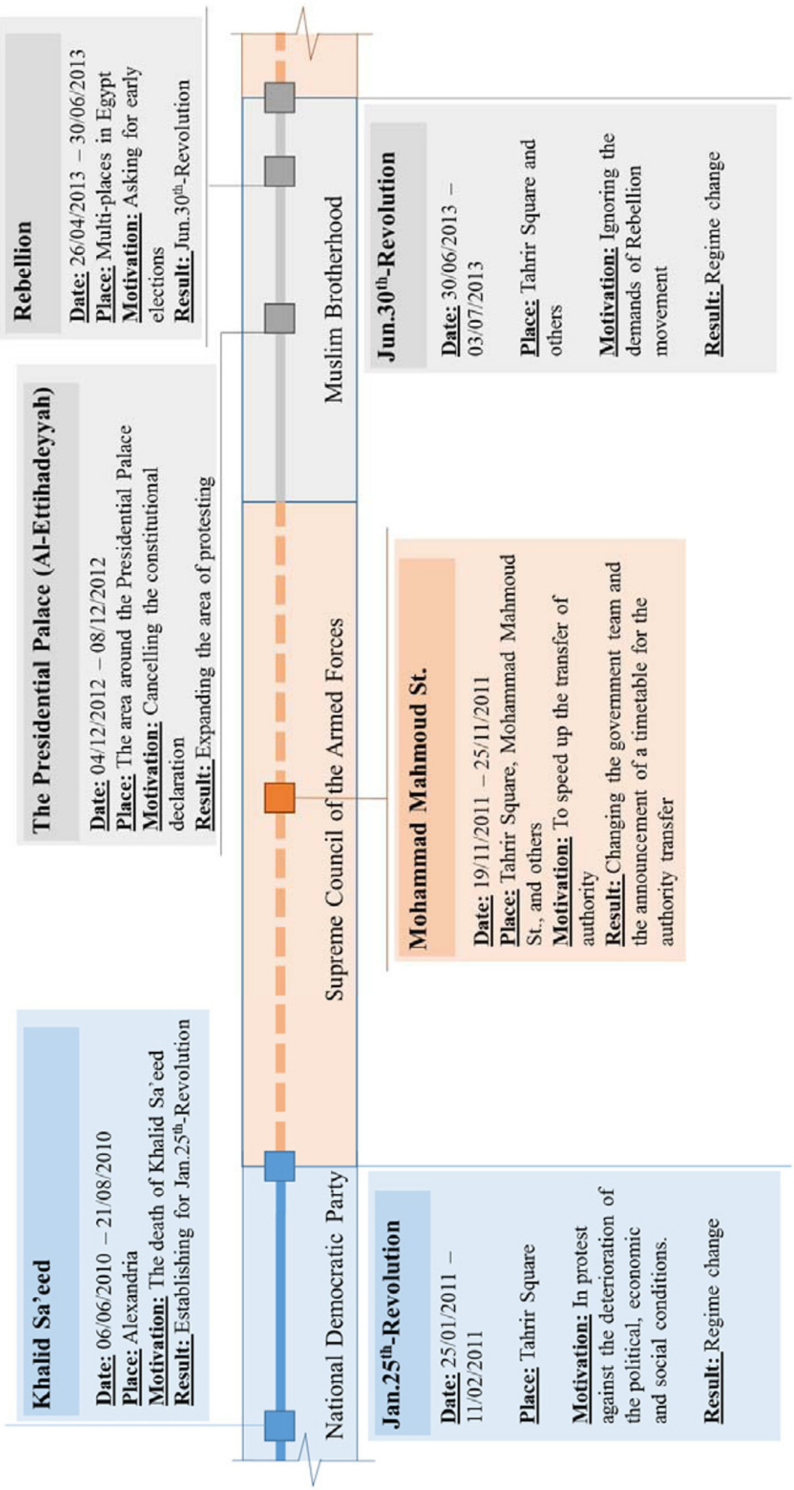

Figure 1: The Case Study Timeline

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Carbon mapping for residential low carbon retrofitting

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Abstract. Worldwide measures towards reducing energy use and CO_2 emissions has become of a prime concern to mitigate the current and to adapt with the future climate change symptoms. Fifty percent of carbon emissions in Egypt result from the residential sector due to the existing energy inefficient building stock. The Egyptian national development targets to reduce CO_2 emission by 20 % by 2020 however the actions taken to reach the target are not promising. This study aims at developing a carbon mapping tool designed to measure the carbon foot print for residential buildings in Egypt and to offer a retrofitting carbon mitigation solutions on both building and urban level. That is through a web tool that will enable to calculate and visualize the carbon emissions of specific existing residential buildings. This web tool also serve as a decision support means for architects and planer during projects planning and design development phases. In addition it supports measuring the impact of housing retrofit and using renewable technologies for energy production. It serves to anticipate occupants' behaviour to form a grid for decarbonisation on town planning and city level. The study is still in its theoretical phase and in the paper we are showing the outline for the tool knowhow and its expected results.

Keywords: Low carbon retrofitting; de-carbonisation; carbon foot print; residential buildings; GIS.

1 Introduction

The current global aim is to mitigate climate change and global warming due to the emissions of GHGs focusing on CO2 emissions. International agreements set targets and unify goals for emission reduction through imposing emission control strategies, such as the Kyoto protocol, and the Intergovernmental Panel on Climate Change (IPCC) which presented methods to achieve 80% carbon emissions reduction by 2050 from the 1990 base emissions (IPCC, 1997, 2000, 2003b, 2006). Building construction industry has an increasing impact on the environment, particularly in terms of energy consumption, raw materials consumption, water use, resulting solid landfill waste and carbon dioxide emission (Newell, 2009). According to the U.S. Energy Information Administration in 2009, buildings accounted for 39% of end use energy consumption and 42% carbon emissions. Residential buildings represent the largest building sector; this explains why it can be the key to reduce energy consumption and emissions (Droutsa et al., 2016).

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The Egyptian government has set a target to reduce CO_2 emission by 20 % by the year 2020. When the target could not be reached, the Egyptian national strategy started putting clear guidelines and standards for reaching for reaching the 20 % by 2030 adopting policies, incentives and strategies that leads to energy efficiency and emissions reduction (GOPP, 2013). According to Hanna (2013), residential buildings in Egypt consumed about 51 TWh and 7 Mtoe energy, which represented 41.10% of total electricity consumption in 2010/2011, with the greatest consumption for lighting (31%), followed by entertainment devices (15%), and fridges (13%). Taking into consideration that the number of residential apartments in Egypt reaches 20 million, and around 6 million mixed use apartments, this draws the attention to immediate intervention for the residential sector. Fifty percent of carbon emissions result from the residential sector due to the existing energy inefficient building stock. In parallel, carbon emissions are rapidly increasing, this is due to the reason that national building codes and regulations do not support the reduction in carbon foot prints. They do not promote the use of energy efficient building methods or using renewables as zero carbon and clean energy sources. In addition the Egyptian government had given permission for using coal as a fuel for power station which ironically makes the situation even worse and makes it difficult if not impossible to reach the planned target. While worldwide, the design of new zero carbon buildings has been widely researched, yet, the potential for zero emission retrofit is less known in Egypt. Noting that the vast majority of buildings that will exist in 2050 have already been built, this calls for more research and development for retrofitting for low carbon residential building stock. This can be performed by the interactions of the carbon emission reduction methods, such as fabric improvements, occupant behaviour and renewable technologies in the urban retrofit design process.

This study aims at developing a carbon mapping tool designed to measure the carbon foot print of residential buildings in Egypt. The designed tool will be in the form of user-friendly web application that is considered as a decision support tool for building designers, planners and business developers, as well as for researchers and scholars. It can be used on a larger scale for public and private organizations seeking decision support tool for contemporary and future low carbon planning. Moreover, it can also be used for a smaller scale application by laymen users seeking reduction in home electricity bills, energy consumption and carbon emission. The carbon emissions data in this tool can also be integrated in 3D Building Information Modelling (BIM). This will enable to calculate and visualize the carbon emissions of specific residential development and retrofitting projects during their planning and design development stages. In addition it supports measuring the impact of housing retrofit and using renewable technologies for energy production. It also serves to anticipate occupants' behaviour to form a grid for decarbonisation on town planning and city level. This tool is based on a pilot project for one of Cairo's neighbourhoods in order to test and validate the data and calculation methods. The project is based on a comprehensive database of embodied carbon inventory data for conventional building materials in Egypt and energy consumption per meter square based on average calculations of annual energy bills for the last 10 years for different neighbourhood connected to the main grid. The tool will be designed in phases and will start by a pilot start for testing its efficiency on a neighborhood scale in Heliopolis, Cairo. Then will be applied on a wider scale to cover the whole country's regions with the help of the GIS database.

2 Literature study

Several initiatives have been carried out to develop methods and tools for achieving low carbon projects. This required developing building sustainability assessment for measuring energy consumption and/or emission reduction. It should be noted that the two targets should not be dealt in isolation, on the contrary, the potential carbon analysis may support decision making in order to meet energy demands within the constraints of carbon emission reduction (Yu and Tan, 2016). The study conducted by Bendewald et al, (2013) compared between three methods. The first, used net zero energy assessment method (ASHRAE, 2008: 3), the later used the ecological footprint method (Olgyay and Herdt, 2004), in addition to the ecological carrying capacity method, developed using data from the (IPCC, 2007) with three main aspects; site development, construction and operation phases. This could be accounted for on the building level, yet, on a larger urban/ city level is still underexplored (Li et al., 2016). A recommended approach uses GIS application for cartographic documentation and geometric data, integrated with short energy audits for the representative buildings (Dall'O et al., 2012), while another, uses targeted short surveys to collect and analyse energy use data (Moran et al., 2012).

2.1 Methods for calculating and benchmarking carbon emissions

Accounting for emissions resulting from Green House Gases (GHG) includes challenges for measuring CO_2, methane (CH4) and nitrous oxide (N2O). The study conducted by Yuen and Kong (2009) showed that GHG emissions can be quantified directly or estimated. Those result from a myriad of biophysical and societal activities, focused and abstracted for CO_2 emission, into the term called 'Footprint' through complicated carbon calculative processes and practices along the supply chain (Ormond and Goodman, 2015). There have been various attempts to define 'Carbon footprint' (Wiedmann and Minx, 2008), yet, the most agreed is 'Carbon footprint is a measure of the exclusive total amount of carbon dioxide emission that directly and indirectly caused by an activity or is accumulated over the life stages of a product'. The concept of carbon footprint has gained a wide popularity, which was mainly driven and diffused by nongovernmental organizations (NGOs), companies, and various private initiatives. Researchers have commonly defined this term as the amount of carbon dioxide emissions contributing to a specific product, company or organisation. Regardless the crucial significance of the carbon footprint, it is still vaguely defined ranging from being simply the CO2 emission to full life cycle greenhouse gas emissions (Pertsova, 2007). Hammond (2007) explained that carbon footprint in a property is the carbon weight of tonnes/person or activity. Haven (2007) added that the carbon footprint analysis of an object include a life-cycle assessment that involve its materials, transportation, manufacturing, usage as well as its disposal at the different development stages. A more comprehensive definition for carbon footprint was given by the Parliament Office of Science and Technology. POST (2006) explaining that it is the total amount of CO2 and other greenhouse gases that are emitted along the full life cycle of any process or product. This amount is expressed as grams of CO2 equivalent per Kilowatt-hour of generation that accounts for the different global warming effects of other greenhouse gases. Pertsova (2007) also defined carbon footprint as an area-based indicator that measures the exclusive total amount of direct and indirect CO2 emissions that could be produced by an activity or a product. These activities involve different stakeholders including the individuals, populations, organisations, companies, governments etc.. The products also include both goods and services.

With the continuous threat of global climate change conditions, the continuous environmental awareness and governmental approaches and policies, researches have been concerned in its calculations. Different attempts have been proposed to estimate the carbon footprint starting from online calculators to complex life cycle analysis and other input-output based methods and tools. Two main methodological approaches are used to calculate carbon footprint as a life cycle analysis/assessment (LCA). These are the Process Analysis (PA) and the Environmental Input-Output (EIO) analysis that are considered bottom up and top down approaches respectively. The suitability of PA-LCA and Input-Output methods are limited in assessing large entities including governments, households etc. and small entities including products and process respectively (Tukker and Jansen, 2006 ; Wiedman et al., 2006). Integrating both methodologies using a hybrid approach is considered an inclusive analysis (Heijungs and Suh, 2006). The aims of the analysis as well as the availability of the required data are the two main variables that identify the methodology that can be used to assess the carbon footprint. The input output analysis is found appropriate for macro and meso systems. It is then suitable to assess carbon footprint in industrial sectors, households, government, etc. (Foran et al., 2005; Weidmann et al., 2007).

Four main quantification methods were identified by the world Resources Institute (WRI and WBCSD, 2011), these are; the emission factor, the mass balance method, the predictive Emission Monitoring System, and the Continuing Emissions Monitoring System. Yet, the emission factor method is the most widely used due to restrictions related to data availability, quality control and cost, yet its accuracy is related to the accuracy of the emission factor itself as well as the activity data. The study carried by Alvarez et al, (2016) highlighted the importance of following an integrated approach combining both organizational and product carbon footprint indicators to achieve a more consistent approach based on a SWOT analysis. Tooke et al, (2014) explained that there are generally two approaches in order to account for energy consumption and carbon emissions; a top down approach starting with the wider urban level and moving to the building level, and a bottom-up approach starting with building level agglomerated into the urban level (Kavgic et al, 2010; Swan & Ugursal, 2009). The first approach is based on macro level data on the national level (Kavgic et al, 2010), while the second one use micro level data employed in physical and empirical models (Kavgic et al, 2010; Keirstead et al, 2012; Heiple & Sailor, 2008), while some studies follow an integration of both approaches (Jaccard, 2005). The study carried by Ozawa-Meida et al, (2013) followed a bottom up approach. It presented a consumption-based carbon footprint study for the De Montfort University in UK to cover the first scopes under the WRI/WBCSD Greenhouse Gas Protocol Corporate Standard. The result stressed the need to implement policies to direct the sustainable supply chain of products consumed in university buildings. This study follows a top bottom approach and focuses on measuring CO2 emissions which can be directly calculated using its carbon content (IPCC, 1997). This requires equations with data on fuel combustion, economic sector, emission factor (IPCC, 2006).

2.2 Calculating CO2 emissions for the building level

Several attempts have been carried out to assess carbon emissions on the material/ product level. Yet, this type of assessment on the building/project is still in its nascent. This explains why several practices, methods and tools exist, which may differ in the scope covered, level of accuracy amount of data required and feasibility of the study. According to the (IPCC, 2007), this accounts for any disruption to the natural ecosystem in the development site, raw material extraction, manufacturing, assembly and installation in the construction site, in addition to transportation along the whole process. Emissions should also be accounted for during the operation phase which includes energy consumption. Some of the available tools are; Carnegie Mellon University's Economic Input Output (EIO LCA) calculator, which produces a macro-level economic estimation of carbon emissions (Hendrickson, Chris, Lave, & Scott Mathews, 2006). Also, process based LCA (also known as ISO 14040 LCA), which provides such as the tool developed by Athena Institure's EcoCalculator which provides even more accuracy (Majeau-Bettez, Hammer Strømman, & Hertwich, 2011).

Recent studies to measure carbon emission include the work of Sookun et al, (2014) based on the Intergovernmental Panel on Climate Change (IPCC) methods, and developed a Carbon budget index-focusing on CO2 emissions. Their calculation was based on the work by Gilbert and Reece (Gilbert and Reece, 2006). Bendewald et al, (2013) developed a computational model using carrying capacity as a baseline for building sustainability assessment. It has been developed into an online resource, Green Footstep (www.greenfootstep.org) to guide developers and decision makers for options for emission reduction and offsetting. It is composed of four main components; 1) the baseline native-site carbon storage, which represents the carrying capacity of the building project, 2) the land use change focusing on carbon storing site components, such as vegetation, and carbon emissions sources in the model result from building 3) construction and 4) operation processes.

2.3 Calculating CO2 emissions for the Urban level

The contribution of GHG emissions is larger is urban areas that may range from 40-70% of total emissions (World Energy Outlook report for the International Energy Agency; Satterthwaite, 2008). National emission inventories are prepared according to the IPCC according to activity data and emission factors obtained from different sectors, but do not consider emissions based on spatial regions. According to Selhi (2015), there is no universally accepted protocol to estimate emissions on the urban city scale because inventories vary with locations, and due to data related problems; accessibility and confidentiality (Chingcuanco & Miller, 2012; C. Ratti, Baker, & Steemers, 2005, 2003; Tooke et al, 2014). On the other hand, researchers tend to define wider system boundary and use the Input-Output method to investigate the total primary energy supply in territorial analysis or the regional statistics of final users (Steinberger & Weisz, 2013). This top down approach supports sustainable policy planning to achieve national targets for reducing energy consumption and carbon emissions (Brown, Southworth, & Sarzynski, 2009; Sovacool & Brown, 2010). Other studies include the work of Sookun et al, (2014), who calculated the emission per unit land area that reveals carbon sinks and emission sources using GIS application. It was applied on a case study in Mauritus to provide information about the flow of carbon for those sectors; Land Use, Land Use Change and Forestry. Also, Li et al, (2016) developed a GIS based simulation method to test the effect of varying urban form and building typology to reduce energy consumption and carbon emissions, taking two urban districts in the city of Macau, China. The study applied two approaches for carbon emission analysis; land use-based and building simulation methods. They concluded that the later is 20% more accurate than the first. The study was finalized by presenting a set of low-carbon urban design guidelines. The study carried by Kneifel (2011), stressed the importance of following an integrated design approach in order to reduce energy consumption by average of 15–20%, and carbon emissions by 9–33% at low to null additional cost, even if using conventional energy efficiency measures. He used life cycle energy savings and cost effectiveness to simulate a wide range of new commercial buildings of different building prototypes and locations. Finally, he used mappings to allow for comparisons on the regional and state levels.

Hence, it is notable that GIS application is used as an analytical mapping method for a number of studies to analyse energy consumption and carbon emission (Sookun et al ,2014; Li et al, 2016; Rylatt et al, 2003). This requires grouping of buildings according to different feature classes, that represent the following; floor area (Jones, Lannon, & Williams, 2001; Shimoda, Fujii, Morikawa, & Mizuno, 2004), building age (Jones et al., 2001; Zhao, Martinez-Moyano, & Augenbroe, 2011; Kavgic et al, 2010), household type (single family, aged couple, etc.) (Shimoda et al., 2004), dwelling type, (detached house or apartment house) (Shimoda et al., 2004), building functional type (Zhao et al., 2011), climate zone (Kneifel, 2011; Zhao et al., 2011), etc. However, the methods differ according to the level of accuracy of data input, the variables defined, such as; microclimate conditions, thermal properties related to buildings' envelopes and last but not least, occupant behaviour (Shimoda et al., 2004), the relation between the feature classes and the investigated query; be it energy consumption and or CO_2 emissions, and whether these methods use dynamic (Yamaguchi, Shimoda, & Mizuno, 2007), or static (Shimoda et al., 2004), simulation for occupants' activity schedule.

On the other hand, some studies used other research methods. The study conducted by Tooke et al, (2014), used airborne Light Detection and Ranging (LiDAR) method integrated with spatial data sets for analysing both building and urban levels. They analysed parameters such as; envelope resistivity, air leakage and solar gains for residential buildings, in order to calculate the baseline energy demand for urban areas in the City of Vancouver, Canada. The study showed that the annual estimates of thermal energy demand match those predicted using the energy simulation software programs. Droutsa et al, (2016) presented an energy performance overview of existing residential building stock in Greece. The analysis considered different parameters, such as building size, period of construction and locations according to national climatic zones. It used data from the EPCs (energy performance certificates), that was issued to comply with the provisions of the EPBD (energy performance buildings directive), and investigated the consequent undertaken energy conservation measures to highlight the commonly adopted refurbishment in relation to each building type. Another study by Sanches-Pereira et al, (2016) targeted the Brazilian residential energy consumption and related carbon emissions as well, and highlighted that attention must be directed towards direct energy consumption from households in different regions. They highlighted that more consumption and emissions result from direct electricity consumption and direct energy consumption for cooking.

3 Methodology

The methodology that will be applied in this project is investigative empirical method using GIS as a supporting tool for data entry, analysis and calculation. The project consists of four main phases. The first phase is data collection phase, it includes gathering data for carbon emissions for the specified study area. The comprehensive database of embodied carbon inventory data for conventional building materials in Egypt and energy consumption per meter square is based on average calculations of annual energy bills for the last 10 years for different neighborhood connected to the main grid. The second step is to test and validate the data and calculation methods using the pilot project. The second phase is data processing phase, it includes Data input using GIS application. The third phase is uploading the data on the web link and the complete design for the tool interface. Phase four: Testing for bugs, traffic and tool launching. The designed tool will be tested first on a pilot project through an open access web site. A user survey is activated to record users' comments and suggestions for further development.

The four phases will be implemented in four steps starting with compiling and categorizing the rule of thumb and guidelines of passive and energy efficient design strategies. That is based on information gathered from in depth literature study for previous research work in energy efficient buildings. Together with recommendations from ASHRAE standards which gives possibility for broader application in different climatic context. Second is the programing and demonstration of a user friendly and interactive open access software based on the set of rule of thumbs and guidelines from phase one. That is through the use of state-of-the-art simulation tools. The engine for this interface is energy plus and Diva. The main software used during the project are listed below. Third step will be testing the validity of the application through a demo workshop with a sample of 30 practitioners to evaluate the application efficiency of and users' satisfaction. Then finally adjusting the comments and feedback from testing the software in phase three.

4 Results and discussion

This tool result aims for both levels of layman and expert architect, designers or planners who do not have the skill in working with building simulation programs. That is to help them follow tested and simulated energy efficiency strategies in their designs. This project offers rule of thumb and decision making guidelines. It help designers to achieve high percentage of energy efficiency and reduction in energy consumption during preliminary designs phases and before the design development phase. This guidelines will help reducing time in design development processing and money spent in simulation phases too. The new about this software is that it will also include advices for operation and management of the building and the development of adaptation, reuse or demolition strategies as well as the use of local materials and construction process that embody energy efficient approaches.

We have deduced from the literature that there are three feasible ways of calculating CO_2 emitted from different building uses, the first way depend on calculating CO_2 according to the energy consumption of the living territories and land uses, the second way depend on calculating CO_2 according to the construction of buildings, the third way depend on calculating CO_2 according to the area and different uses of the buildings.

Table (1) Hybrid figures for carbon emissions for different residential building clusters.

Building type		G CO2 / m2
Mixed Residential	Above Average	30
	Average	24
	Low	20

In figure (1) The steps used to calculate CO2 emission for different building uses along the chosen district:

Here is the model that has been created to be run in GIS to calculate the CO2 emission.

The following steps are the outcome of the tool design steps created by suing GIS:

-Create a field (double) named CO2_emission_building_uses in the feature class building_uses_pattern and then select by attribute building_uses_pattern = Mixed Residential above average, then field calculator on the double field to write the following equation = (Shape area in m2 * 30 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Mixed Residential average, then field calculator on the double field to write the following equation = (Shape area in m2 * 24 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Mixed Residential low, then field calculator on the double field to write the following equation = (Shape area in m2 * 20 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Administrative, then field calculator on the double field to write the following equation = (Shape area in m2 * 67 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Hospital, then field calculator on the double field to write the following equation = (Shape area in m2 * 88 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Commercial, then field calculator on the double field to write the following equation = (Shape area in m2 * 164 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Cultural, then field calculator on the double field to write the following equation = (Shape area in m2 * 35 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Education, then field calculator on the double field to write the following equation = (Shape area in m2 * 13 /1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Entertainment, then field calculator on the double field to write the following equation = (Shape area in m2 * 80 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Religious, then field calculator on the double field to write the following equation = (Shape area in m2 * 56 / 1000).

-In the feature class building_uses_pattern and then select by attribute building_uses_pattern = Utilities, then field calculator on the double field to write the following equation = (Shape area in m2 * 125/ 1000).

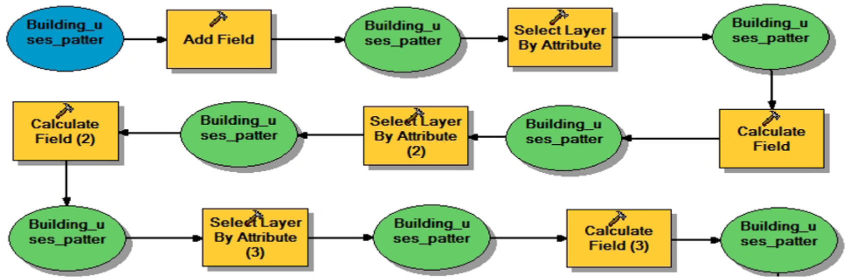

Figure (1) The steps used to calculate CO2 emission for residential building. The model has been created to be run in GIS to calculate the CO2 emission.

Finally by running this model the following table is generated:

Table (2) CO_2 Building Use Emission.

Building use	CO2 Emission Ton/year
Mixed Residential Above Average	17.8647
Mixed Residential Average	129.1622
Mixed Residential Low	3.2087

5 Conclusion

This research project is to create a user friendly decision making tool for architects and building designers. It is a guide for best practices and rule of thumb to be used during the process of designing carbon neutral and plus energy buildings using building modelling simulation programs. The focus is on residential house design which is based on climate-responsive and passive design strategies for built form, orientation, layout and envelope. This tool will also advice on design strategies that reduce carbon emissions for operating energy of the building. In addition will help in informing the designers with predicting actual energy usage. This tool also can be helpful for retrofitting and rehabilitation design. This project idea came from believing that the climatic responsive decisions should be made early during the design process and from believing that architects and designers are sole responsible for reducing energy consumption in buildings. In that respect this digital interface guide for best practices aims to assist the target group to develop and apply carbon neutral and energy efficient strategies in their designs for the enforcement of such strategies during the building operation and occupation. That explore the impact that building geometry, construction materials and integration of renewable energies has on operational energy consumption. Also the objective is to offer a user friendly interface guide that is considered a cost efficient decision making tool for designing carbon neutral and plus energy buildings. We hope after the completion of this study, our tool will help in reducing the about of CO2 emission in the residential building sector in Egypt and to reduce expenses paid for consultancy in energy auditing with the help of experts in simulation programs which normally hinder architectural firms and clients to pay such consultation fees.

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Towards sustainable slums: understanding fire engineering in informal settlements

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Abstract. Around one billion people (UN 2012) worldwide live in informal settlements (also known commonly by the more derogatory names of slums, ghettos, shantytowns etc.), and these areas are often ravaged by fires. This paper presents an overview of the problem of fires in informal settlements and provides an understanding of fire engineering such that problems can be better addressed. Research work is based primarily on data from South Africa, especially Cape Town, although the research is generally applicable to areas worldwide. Informal settlements can become more economically, socially and environmentally sustainable when dwellings, or "shacks", are not being regularly razed to the ground. An introduction to fire dynamics in small enclosures is provided and related to informal settlement dwellings, and it is shown how such behavior influences possible solutions. Discussions seek to bring data already well-known in the social science realm into the engineering field such that the problem can also be understood and addressed by engineers and fire scientists. Input parameters for fire models are outlined.

Keywords: Informal settlements, fire safety engineering, sustainable slums, poverty; fire loads; shacks.

1 Introduction

Fire engineering "is the application of scientific and engineering principles, rules, codes, and expert judgement, based on an understanding of the phenomena and effects of fire" (IFE, 2014). Its aim is to reduce to acceptable levels the chance of loss or damage due to fire. Due to the very nature of informal settlements, (i.e. lack of municipal control, highly variable layouts, limited facilities, minimal financial resources, social unrest etc.) engineers and scientists have often ignored the problem of fire in informal settlements, since interventions are often difficult to implement and sometimes unsuccessful.

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In South Africa the problem of fires in informal settlements is significant. In an interview with the chief fire officer of Cape Town, Ian Schnetler, he noted regarding informal settlement fires in Cape Town that ‘there’s only four of five days on average a year when we don’t respond to one’. An area named Masiphumelele experienced an extensive fire in December 2015 where approximately 1000 homes were destroyed and 4,000 people left homeless (Turok 2015). Birkinshaw (2008) estimates that there are around ten shack fires a day in South Africa (SA). Pharoah (2009) explains that at least one third of the population of SA live in informal settlements, and in the Cape Town region the number of informal dwellings increased from around 28,000 in 1993 to over 104,000 in 2006. A strategic framework has been developed in the Western Cape to try address burn injuries as yearly there are a total of around 500 deaths and 15,000 hospital admissions in due to fire (DMFRS 2015), many of these from informal settlements. Fig. 1 shows the before and after images of a large fire in Langa, Cape Town, in March 2012. Fires spread rapidly through such densely populated areas.

Fig. 1. (a) Informal settlement of Langa, Cape Town, before a fire, and; (b) the same area after a fire (CoCT Fire Rescue 2013)

2 Potential solutions

A variety of solutions have been proposed for improving fire safety in informal settlements. However, with the challenges of finding solutions that are relatively inexpensive, require minimal maintenance, cannot be stolen or vandalized, and can easily be implemented in wide range of scenarios there is certainly no “one-size-fits-all” solution. Current solutions being tested and implemented in South Africa include heat detectors, intumescent paints that make shack walls fire retardant, improved cooking stoves, fire breaks of various kinds, training of local communities, and new construction materials, amongst others. The Western Cape Disaster Management Fire & Rescue Services have been pioneering innovative low cost smoke alarm systems which are currently being rolled out (Eksteen 2016). The question to now be asked is: how can solutions be evaluated based on engineering sciences and how do low income dwellings behave in the event of a fire?

3 Fire dynamics applied to informal settlements

The physics of enclosure fire dynamics will be explained relative to Figures 2 and 3. The former is a modified version of the well-known fire triangle illustrating the processes necessary for combustion to occur. The second figure is a time-temperature graph showing the behavior of different fires. For more detailed information on fire behavior refer to Drysdale (2011) or Karlsson & Quintiere (2000). For a fire to occur heat must vaporize fuel, and the resultant gas then combines with oxygen and undergoes the complex chemical reaction of combustion, which then releases further heat. As the amount of heat in an enclosure increases more fuel is vaporized which causes additional items within the enclosure to ignite and the fire to spread. Once the hot layer of gas that builds up in the enclosure is deep enough that it extends down to encounter objects such as furniture and carpets in a room it causes all the objects in an entire enclosure to spontaneously combust. This is the phenomena known as flashover, as noted in Fig. 2, and it is associated with a rapid increase in temperature as energy is released. If the rate of combustion is limited by the amount of available oxygen the fire is referred to as a ventilation controlled fire (the blue line on Fig. 3) whereas when the amount of fuel available for combustion limits the burning rate it is referred to as a fuel controlled fire (the magenta line). Smouldering fires (orange line) are those associated with flameless combustion, low-temperature and slow or no growth. For medium to large enclosures peak temperatures can occur for around 30 minutes, depending on geometry, but for small shacks full burnout and collapse can occur in as little as 2-5 minutes (further research required to define accurately). It is hypothesized that traditional fire zone models cannot be used for shacks in isolation as they collapse so rapidly.

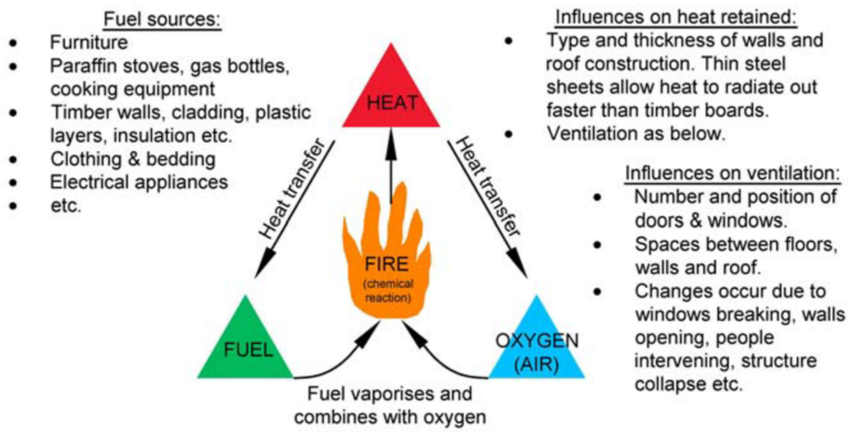

Fig. 2. The fire triangle modified to suit informal settlement dwellings

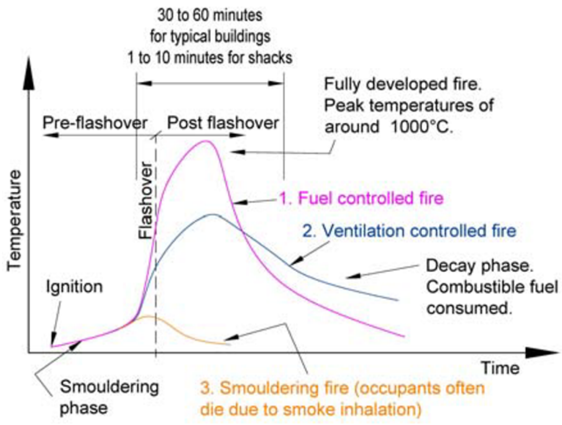

Fig. 3. Time-temperature behavior of fires

With an understanding of enclosure fire dynamics the behavior of shacks in fire will now be addressed, considering Fig. 4. The most important variables are those related to the amount and type of combustible fuel, the influence of ventilation on oxygen levels, and the influence of enclosure conditions in terms of either releasing or retaining heat.

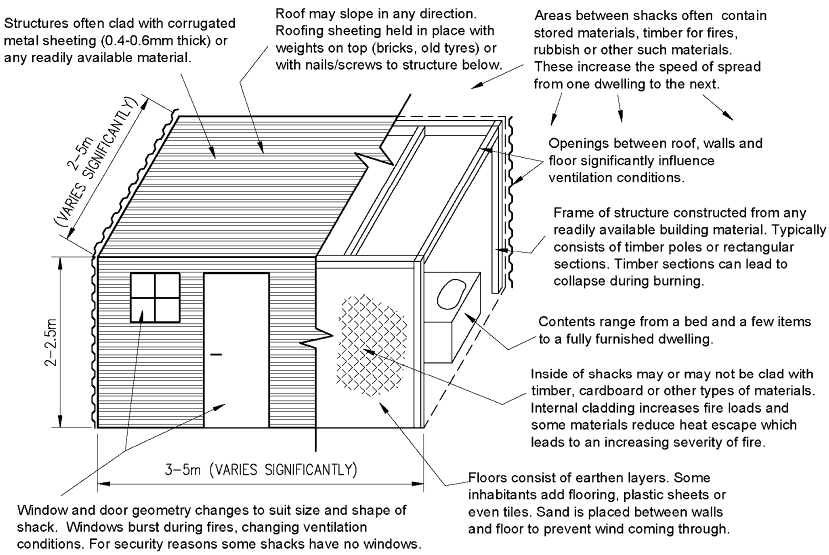

Fig. 4. Anatomy of a shack in relation to fire behavior

The fuel load in informal settlements is highly variable. A preliminary investigation has indicated that average fuel loads are in the order of 400-500 MJ/m^2 (Maree 2015), although may be as high as 1000-3000 MJ/m^2 for dwellings storing combustible materials and fuels. These average values are comparable with those suggested by the Eurocode 1-1-2 (BSI 2002), with an office at 420 MJ/m^2 or a European dwelling of 780 MJ/m^2. Fuel content values are heavily influenced by the presence of the items listed in Fig. 3 including furniture, cooking apparatus such as paraffin stoves, cardboard or timber for walls and roofs, bedding etc. Fuel loads may be time-dependent because during a fire people often try to save belongings so move them into aisles or open spaces near their dwelling. This can make evacuation and firefighter access significantly more difficult as aisles, which are already narrow, become blocked. There are a wide variety of ignition sources for fuels including: falling candles, electricity faults, arson, cigarettes, exploding paraffin stoves, fires for heating or cooking getting out of control, etc. (DMFRS 2015).

Smouldering fires often kill people as people die from the rapid depletion of oxygen and smoke generation in these confined spaces, and this is typically exacerbated by high levels of substance abuse (Eksteen 2016). Typically deaths occur in the shack of origin and deaths in subsequent dwellings are far less common. Once flaming fires occur they can easily spread from one dwelling to another based on the close proximity of adjacent houses, the high amounts of combustible material available, suitable ventilation conditions, etc.

For a typical dwelling there is at least one door, with the number of windows varying to suit the size and layout of the shack. Some shacks have no windows due to security concerns. Windows will typically break during a fire, resulting in non-constant ventilation conditions. Also, with the poor quality of construction encountered there are often spaces between walls, the roof and floor. Around floors sand is typically used to seal these spaces, whereas between walls and the roof materials such as paper is pressed into openings. In the event of a fire the door may be closed or open, with the former being more probable for the shack of origin.

Boundary conditions of shacks significantly influence the amount of heat retained during a fire. Underneath steel sheeting inhabitants will often try to install cardboard, timber or other materials, when available, to provide insulation in summer and winter. It is hypothesized that the presence of certain boards will trap heat within an enclosure, increasing the severity of fires, and this hypothesis is currently being tested. Also, cladding increases the amount of available combustible material. The steel sheeting used can easily warp and buckle, which may change ventilation conditions. If the amount of ventilation increases more than required it can actually result in a cooler fire as cool air is entrained, thus reducing rates of fuel vaporization. Hence, it should not be assumed that when ventilation increases it will always lead to a hotter fire, in fact the opposite is possible. It may actually reduce fire spread if the roofs of burning shacks could be removed to vent heat upwards, although practically this is normally not feasible and shacks may collapse when this is done.

4 Conclusions and considerations

From the explanations regarding fire behavior it can be seen that any solution proposed needs to consider the highly variable nature of fires in informal settlements. Also, social and cultural considerations play a significant role in the effectiveness of any solution, often in excess of technical factors, and these social issues have not been addressed above. In light of such discussions above it is hoped that those developing solutions for informal settlements can better understand fire dynamics and produce more suitable interventions, whilst understanding that there is no "quick-fix" to this massive social and technical problem. Fire behavior in the paper has been qualitatively described to assist understanding, and future publications will focus on providing quantitative data.

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Cooling the Future: Bridging architectural aspects from the past with modern energy efficient paints

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Abstract. This paper presents the importance of building's envelop protection, the role of the building materials, the technologies and approaches involved and how the development and the use of modern high albedo coatings, based on traditional and mineral binders, could have a significant contribution in Mediterranean building's energy performance.

A number of inorganic, white and coloured, high solar reflective and breathable coating materials, based on natural and traditional binders (.i.e. waterglass, lime, natural pozzolans), synthetic and natural pigments (.i.e. burnt sienna) and/or unlimited resources (i.e. sand) have been developed.

The use of such coatings in built environment and especially on building's envelope, as a passive cooling technique, enable the improvement of indoor thermal comfort conditions and the reduction of cooling loads, driving to lower carbon dioxide emissions and to significant energy savings.

Keywords: High solar reflectance, passive cooling, vernacular architecture, functional paints, historic buildings, urban heat island, energy savings, thermal comfort

1 Introduction

The protection from unfavorable, harsh climatic conditions and achieving comfortable microclimate are the primal objectives of architecture. The Mediterranean traditional architecture evolved to produce buildings that would be in harmony with the harsh climates of its various regions (D.Serghides, 2010). Vernacular architecture adheres to basic green architectural principles of energy efficiency and utilizing materials and resources in close proximity to the site. These architectural principles capitalize on the native knowledge of how buildings can be effectively designed as well as how to take advantage of local materials and resources (Sarah Edwards, 2011).

2 Building envelope and passive cooling

Envelope design as a means of passive cooling is an integrated part of building design form and materials as a total system to achieve optimum comfort and energy savings

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(E.M. Okba, 2005). The building envelope is considered the selective pathway for a building with climate-responding ability with respect to cooling, ventilation and natural lighting needs. In hot and dry climate and because of heat gain due to solar effects, significant amount of energy is consumed to sustain comfortable indoor environment (Projacs Academy, 2013).

The materials surrounding the occupants of a building are of prime importance for protection against heat and cold. Great care must be taken in the choice of the wall and roof materials and their thickness with respect to their physical properties, such as thermal conductivity, resistivity and transmission and optical reflectivity.

There are many types of roofs in traditional Egyptian vernacular architecture, constructed from local materials and with traditional techniques. In hot-arid regions the dome, the vault and the flat roofs are considered traditional roof shapes. The modern construction method, in which a 10 to 15 cm exposed concrete slab is created, is considered the worst possible roof for this climate, because the surface temperature of the inner slab can reach up to 60°C, which is stored till late in the evening (P. Gut, D. Ackerknecht, 1993).

As the roof is a critical part of the building, high solar reflective and emissive materials are required for long-wave radiation, as well as thermal insulation. Apart from the fact that insulation is essential for concrete flat roofs, they also need an additional and expensive, robust skin that protects the insulation layers from damage caused by the sun (Mostafa El Gamal, 2012).

3 Buildings' envelope traditional construction materials

Building envelope in traditional architecture was constructed of local building materials that were appropriate to ambient environment whether in physical properties to climatic conditions or the construction techniques employed by the society that produced this architecture. Traditional building materials, such as brick, stone, palm trunks, and wood are usually natural, so they are generally low in embodied energy and toxicity. Often, traditional building materials are local and better suited to climatic conditions; thus, they create comfortable internal environment passively and naturally. Generally speaking, they are low embodied energy, recyclable, reusable, energy efficient and environmentally sustainable.

Building materials strongly influence vernacular building traditions also. It should be noted that many vernacular dwellings observed combine massive walls with lightweight roofs, most frequently thatch roofs. As the climate becomes hotter and more humid, lightweight building envelopes and construction materials become more prevalent. In hot-arid regions the vault, the dome and the flat roof are the traditional roof shapes.

The use of thatch appears to be especially prevalent. The most common application of thatch in recent European traditions is for roofs, but many cultures, including prehistoric Britons, used thatch for the entire structure. Roof materials in vernacular dwellings included stone (slate), tile, thatch, bark, skin, felt, wood or turf. Tile roofs are a common site in vernacular architecture, but have very poor insulting quality. Thus, tile roofs are combined with thick wood, masonry or earthen layers except in cases of mild environments like the Mediterranean where terracotta tiles were developed by the Romans in conjunction with mortar (Paul T. Nicholson, 2000).

3.1 Traditional building materials examples

The use of natural building materials such as stones and mud bricks has always been an essential element of vernacular architecture. The mud bricks were produced by mixing the mud with sand and chopped straw, a technique still used today. Mud bricks were used in the construction of many Pharaonic tombs and houses (Zhiqiang Zhai, 2010). Natural stones are another common material of traditional vernacular architecture, recognized for their durability and high thermal capacity (Baran Tufan, 2014).

Lime and gypsum mortars were used extensively in various structures, employed mainly as plaster coatings. The chemical composition of lime and gypsum binders is identical to that of the corresponding natural rocks, although their microstructure is different. In the Levant (Syro-Palestine coast), Anatolia and Greece, lime plaster was almost exclusively the material of choice. Recent studies have shown that in ancient Egypt, lime was also used in this region (J.W. Shaw, 2009). The need to increase the poor resistance of quicklime mortars and improve hardening, even in water (e.g., for the construction of support foundations for bridges and aqueducts) led Roman builders to develop mortars containing pozzolana or other materials which behaved in a similar way (e.g., brick dust): these were the forerunners, by more than 2,000 years, of a material similar to today's Portland cement (J.D. Friedman, 1971). These mortars can be manufactured by mixing lime with pulverized clay materials called pozzolans (natural or artificial). When finely ground, the pozzolans react with lime at normal temperatures in the presence of water or moisture to form stable calcium silicate/aluminate hydrates. The hydraulic character of such mortars is due to the reactions between the pozzolanic material and the lime binder (Carlo Giavarini, 2010).

For many years the use of traditional lime-based paints was restricted to those involved in the conservation industry, but more recently these paints have enjoyed a renaissance. The basic material of limewash, lime, is derived from limestone or chalk (both are forms of calcium carbonate) which is 'burnt' in a kiln to form quick lime (calcium oxide). To make limewash this material is then further diluted with water to form a thin paint of brushable consistency (Maria Philokyprou, 2010). Limewash has always been, and remains, a most effective way to protect, maintain and beautify the surface of historically-significant structures (Peter Mold , 2005).

Other known painting technologies that have been used, involve chalk, casein (non-fat milk curds), animal or vegetable glues (i.e. Egyptian gum), and oil. Traditional distemper paints are also generally known and appreciated for their soft luminous appearance.

4 Colours, pigments, renders, paints and coatings

4.1 Colour

Isidore of Seville (560 – 636), scholar in the early middle ages described paint as "captured sunlight". Thousands years later, a number of technical standards describe the measurement of colour as follows: "Colour is the property of an area in the field of view that seems to have no structure and which allows this area to be differentiated, on viewing with one unmoving eye, from a similar structure-less area bordering on the original and seen at the same moment".

4.2 Paints and coatings

Colours in all shades are used to decorate buildings. Paint does not, however, simply add colour, but is also a structural component, providing protection against the weather, moisture, water and against atmospheric, chemical, biological, mechanical or other influencing factors. In addition, paint has a decorative element. The term "coating", which includes the traditional terms paint, varnish and lacquer, today also includes a large number of protective systems including filling compounds and floor coatings. Coating materials as defined in modern technical standards – paints and varnishes – are liquid to pasty, or powdered materials, which consist of binders, pigments or other colouring matters, fillers, solvents and other ingredients. Paints or coatings in general, consist of binders, solvents, fillers, pigments and auxiliary substances. These ingredients, which are added and mixed in the solid or liquid state, determine the colour and above all the properties of the paint. Binders can be divided, according to their origins, into vegetable, mineral, animal and synthetic binders. EN 1062 lists the following binder groups: acrylic resin, alkyd resin, bitumen, cement, chlorinated rubber, epoxy resin, slaked lime, oil, polyester, water glass, silicone resin, polyurethane, vinyl resin.

4.3 Plastering/rendering

Plastering/rendering, as defined in many standards, is a single - or multi-layer coating of plastering or rendering mortar applied to walls or ceilings with a defined thickness. Its final properties develop only after hardening. Mineral binders can be divided into the following groups: lime binder, calcium silicate binders, calcium aluminate binders, calcium sulphate binders and silicate binders. Beyond mineral plasters, synthetic plasters based on organic binders are available also. Synthetic resin plasters are coatings which look like plaster. They are made of organic binders and fillers/aggregates in the form of a polymer dispersion or solution (Alexander Reichel, 2004).

4.4 Pigments and colorants

Ever since the prehistoric time, mankind took delight in coloring the objects of daily use by employing natural pigments of vegetable, animal, and mineral origin. These coloring substances, known as natural dyes, are the chemical compounds used for coloring fabrics, hair, leather, plastic, paper, food items, cosmetics, and medicines, etc., and to produce artistic colors and inks for paintings and printing (Har Bhajan, 2014).

Natural dyes have been used in most of the ancient civilizations of the world, like India, China, Mesopotamia, Egypt, Greece, Aztec, and others. The discovery of red ochre in very ancient burial sites indicates that the use of natural dyes for aesthetic and other purposes is at least 15,000-year old. The art of dyeing cloth is believed to have been known since 3000 BC in China and 2500 BC in India. At relatively the same period (2000 BC), dyeing of cloth in yellow, red, blue, and green was also practiced in Egypt.

Earth pigments are naturally occurring minerals, principally iron oxides that people have used in paints for thousands of years for their natural color. These natural pigments are found in rocks and soils around the world, where different combinations of minerals create vibrant colors that are unique to the regional landscapes. Some earth pigments are roasted in order to intensify their color. Earth pigments include ochres, sienna, and umbers. Ochres come from naturally tinted clay containing mineral oxides. Ochres are available in a range of yellows, golds, and reds. Sienna is a form of limonite clay. The pigment was first used in Italy in prehistoric times. The unique color is derived from ferric oxides. Umber, is a clay pigment that contains iron and manganese oxides. The name is said to be derived from the Latin word umbra (shadow) or from the mountainous Italian region of Umbria, where umber was originally extracted. Umber is darker in color than ochres and sienna. Colors range from cream to brown, depending on the ratio of iron and manganese compounds. Mineral pigments are pigments that are created by combining and heating naturally occurring elements. Mineral pigments made by heating sulphur, clay, soda. They include ultramarine and spinel pigments.

5 Cooling Mediterranean homes naturally and affordably

5.1 The concept of high albedo materials

Keeping cool indoors when it is hot outdoors is a problem. The sun beating down on our homes causes indoor temperatures to rise to uncomfortable levels. Air conditioning provides some relief. But the initial costs of installing an air conditioner and the electricity costs to run it can be high. An alternative way to maintain a cool house or reduce air-conditioning use is natural (or passive) cooling. Passive cooling uses non mechanical methods to maintain a comfortable indoor temperature.

Dull, dark-colored typical home exteriors absorb 70% to 90% of the radiant energy from the sun that strikes the home's surfaces. Some of this absorbed energy is then transferred into the home by way of conduction, resulting in heat gain. In contrast, shade trees and bushes can reduce this heat gain and typical light colored surfaces can reflect most of the heat away from the surfaces (Cooling Your Home Naturally: DOE/CH10093-221 FS 186, 1994).

The most effective method to cool a house is to keep the heat from building up in the first place. The primary source of heat buildup (i.e., gain) is sunlight absorbed through the roof, walls, and windows. Secondary sources are heat-generating appliances in the home and air leakage. Reduction in roof heat gain means reduction in cooling demands, using air-conditioning so as to increase human indoor thermal comfort levels. This also has a positive impact on urban environmental quality. The performance of the roof depends mainly on its form, construction and materials. Generally when the roof surface is fully protected from the direct warming effect of solar rays, especially at noon, heat gain is minimal (Marwa Dabaieh, 2015).

Wall color is not as important as roof color, but it does affect heat gain and in some cases notably. White exterior walls absorb less heat than dark walls. Light, bright walls increase the longevity of siding, particularly on the east, west, and south sides of the house. Lower exterior walls surfaces temperatures, will gradually affect the buildings' interior temperature also. When the wall internal surface temperature is lower than the indoor air temperature, it will have cooling effect. This reduction of the wall internal surface temperature is beneficial to improve the body's radiation heat transfer and enhance the indoor thermal comfort effectively in summer. Therefore, the cooling effect of the internal surface temperature may reduce the air-conditioning running time, to achieve the goal of energy saving.

Albedo indicates the fraction of incident radiation, including the invisible ultraviolet and near-infrared parts of the spectrum that is reflected. Planet Earth now has an average albedo of 0.3 that is. It reflects about 30% of the sunlight that lands on it (Tina kaarsberg, 2006).

The albedo of a surface is defined as it's hemispherically and wavelength-integrated reflectivity. This definition applies to simple uniform surfaces as well as to heterogeneous and complex ones. Typically, urban albedos are in the range 0.10 to 0.20 but in some cities these values can be exceeded. North African towns are good examples of high albedo urbanized areas (albedos of 0.30 to 0.45) whereas most US and European cities have lower albedos, from 0.15 to 0.20 (Haider Taha, 1997).

High albedo materials drive to lower temperatures of the surfaces exposed to solar radiation than those characterized by more traditional materials, thus having a lower temperature characterizing the environment (Ferdinando Salata, 2015).

Cool roofs, or high albedo roofs, reflect a large portion of the sun's heat, and have a greater ability to emit, or radiate away, any heat that is absorbed. The ability of a cool roof to perform these functions is measured in terms of solar reflectance (also known as albedo), thermal emittance, and Solar Reflectance Index (SRI).

Cool roofs can help reduce the heat island effect and also help improving the energy performance of the buildings. A cool roof can reflect the sun's heat and emits absorbed radiation back into the atmosphere at a higher rate than standard materials. The cool roofs technology has been used for more than 20 years (EPA, 2012). The cool roof basically helps in reflecting sunlight and heat, thus reducing the temperature of the roofs. 20---25% of the urban surface is reported to be occupied by roof surface.

This provides huge scope of providing passive cooling to enhance energy performance of the modern buildings (Zinzi & Angoli, 2012).

5.2 The concept of coloured high solar reflective coatings

A number of coloured high solar reflective coating materials (Fig 1) have been developed which allow architects and buildings' energy consultants to take benefit of lower surface temperatures, without sacrificing aesthetic options in building's design. The technology involved enables the creation of dull, dark-coloured even surfaces, with significant higher solar reflectance and infrared emittance values, in comparison to standard materials of the same colour.

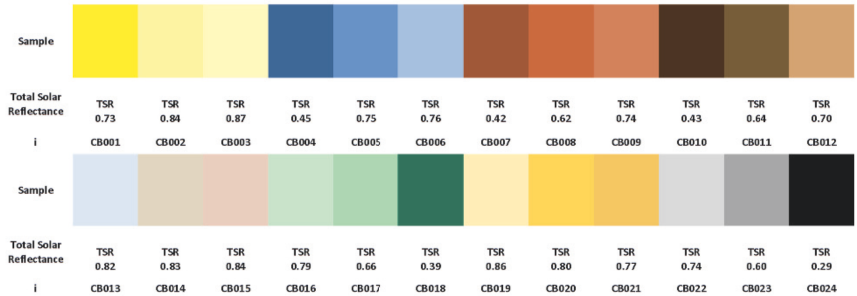

Fig 1. High Solar Reflective Colours Source: www.abolinco.com

While a typical black colour absorbs almost all thermal radiation the "cool" alternatives can even reflect the 30%. As a consequence, the use of such low heat build-up colours in the built environments can have a significant impact in lowering surface temperatures: driving into buildings' energy demand reduction for cooling and to better microclimatic thermal conditions. Typical applications of such coatings are not limited to commercial or residential buildings and urban superstructures.

Historic or cultural heritage buildings can also take advantage of such coating solutions. Even though historic buildings are currently exempted from most energy performance directives and requirements, there is a growing awareness that cultural heritage preservation and preservation of the natural basis of life are equally important goals.

Statistical data on historic buildings in Europe (Alexandra Troi, 2014) indicate that 14 % of the EU27 building stock dates from before 1919 and 12 % from between 1919 and 1945 (with considerable national differences), corresponding to thirty and fifty-five million dwellings respectively, with 120 million occupants. Finding conservation-compatible solutions for these buildings can thus contribute a significant share to the EU's $CO2$ emission reduction goals.

5.3 The concept of "natural" binders and special pigmentation mix design

In respect to the well-performing of the traditional building materials since centuries, societal claims for greener technologies and taking into account recent technological developments and technical requirements, a number of high solar reflective coating materials based on minerals and/or hybrid binders have been developed. The result is breathable, yet water resistant, coating materials, which combine the inherent function, the characteristics and the intended scope of traditional construction materials, with novel and advanced performances and functionalities.

From another aspect, carefully selected formulations, managed to combine natural earth pigments with high performing non-toxic metal oxides and nanostructured raw materials. As a result, a number of high solar reflective colours are available, that have the same visual properties with traditional colours used, in many Mediterranean countries. The new high solar reflective coating materials are not limited to lime paints and stucco, natural pozzolanic mortars and silicates.

6 High solar reflective materials and energy savings

Several studies have been performed in the past to evaluate the impact of the high solar reflective technique on the energy performance of air- and not air-conditioned buildings (M Zinzi, 2010). Reducing the building's solar gains, the energy use for cooling and the peak electricity demand will be reduced also in summertime. This strategy will conversely lead to increased energy consumption during the heating months. Solar gains are reduced in this season, since the sun is low on the horizon, with a reduced length of day and sun radiation. These reasons make solar reflective technique an energy-efficient strategy, but several variables have to be taken into account in order to evaluate the counterbalance between cooling benefits and potential heating penalties. Such variables include:

- Climatic conditions: The warmer the building location, the higher the needs for cooling.
- The insulation level of the building. This aspect has to be connected with the climatic conditions.
- Building use.
- Building geometry and orientation.
- Installed energy systems.

7 Conclusions

Vernacular architecture in many countries within the Mediterranean area is a splendid example of how built space skillfully adapted to a harsh natural setting, taking advantage of local materials and techniques. The use of solar reflective building materials is a traditional, simple and cost effective technique, which, through proper design considerations, can drive to a clear benefit into buildings' energy consumption for cooling.

The development of novel, durable and coloured solar reflective coating materials, based on natural binding agents, who ‘‘mimic’’ the characteristics of the traditional material used for centuries in vernacular architecture and outperform their intended scope, can be a well suited technique in buildings' energy renovation works and especially into historic buildings applications.

Moreover, the benefits from the use of such materials can have a positive impact into microclimatic conditions (mitigation of urban heat island consequences) and be also an effective answer to global warming, which is critical in large urban areas.

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Part II
Energy

Proposed District Cooling Plant For The British University In Egypt Campus

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Abstract. Egypt suffers from a major shortage in the produced electrical energy compared to local energy consumption. In order to solve the electricity crisis in Egypt, there must be alternatives to the traditional electric systems, which will reduce the electrical consumption significantly. One of those solutions is the district cooling concept. District cooling plant is proposed to be constructed at the British University in Egypt to serve the main seven buildings of the university campus. The current cooling system installed in the campus is composing of Direct Expansion (DX) splits and air handling units for all the university buildings, except for the main auditorium building which is supplied by chilled water from three reciprocating chillers. The current system cooling capacity is found to be $1882.3\ TR$ which is resulted from combining the nominal value for each installed DX unit and for each chiller capacity. However, the proposed district cooling plant shows great reduction in the cooling load required as proved from comprehensive calculations using the hourly analysis program (HAP) that the total coincident load of the proposed plant has found to be $1284.6\ TR$.

The proposed primary cooling plant composes of three centrifugal chillers which is considered to be the most convenient chiller configuration for the university premises due to the variable cooling load, low part load and unavailability of natural gas pipelines needed for some other chillers type such as absorption chillers.

Keywords: District cooling; running cost savings; optimum chillers configuration; energy optimization

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Nomenclature

ASHRAE American Society of Heating, Refrigeration and Air-conditioning Engineers
D Pipe diameter (m)
DE District Energy
DX Direct Expansion
ETS Energy Transfer Station
GPM Gallon Per Minute
HAP Hourly Analysis Program
HVAC Heating, Ventilation and Air Conditioning
IDEA International District Energy Association
Kwh Kilo Watt hour
TFM Transfer Function Method
TR Ton Refrigerant

1 Introduction

Nowadays air conditioning is consuming a great share of the total electricity produced and thus power and energy savings are needed to solve the dilemma of shortage of electricity sources. According to study carried out by university of Madrid (Izquierdo 2011), air conditioning uses one third of the total electricity used by residential buildings in summer. Not to mention the use of air conditioning in service is also using significant amount of electric energy; the data centres such as server rooms consumed about 61 billions of kilo watt hour (Kwh) in 2006 and about 63% of these wattage is owing to air conditioning (Brager 2001).

The paper will be divided as follows; firstly the HAP software methodology will be discussed to show how the cooling load is being calculated. Then the friction losses associated with the pipe hydraulic study and duct sizing will be explained. The details of the full design calculations will be summarized in the case study section; where the methodology of the plant location selection will be presented. The district cooling load will be then calculated using the peak coincident load concept and compared to the actual installed system. Moreover the chillers configuration will be mentioned with the specifications of the chosen chillers. Then buildings D and H will be taken as case study for the pipes and ducts design calculations respectively. In addition, energy analysis will be made to give a recommendation about the optimum operating hours of the system to have minimum energy consumption.

2 Methodology

2.1 HAP design and simulation module

The cooling load analysis is based on using the certified ASHRAE software called HAP, where the cooling load is calculated using the transfer function methodology (TFM). TFM is simply a derivative of heat balance method, the heat balance equations are used once to derive the TFM coefficients and then those coefficients are used repeatedly to calculate cooling loads as quickly as possible (Tashtoush 2005). Hence with reduced number of inputs and with using coefficients multiple times, this will make TFM is an efficient and practical method to account for the cooling loads. So for example, TFM will not account the heat transfer coefficients (U values) for all the walls and roofs, however the set of heat transfer differential equations will be solved to get the TFM coefficients that will be used thereafter. In addition, the TFM uses the space air transfer functions (heat extraction equations) to account for the effect of changing room air temperature on the cooling load.

The transfer function is set of coefficients that relate an output function at some certain time to the value of the driving functions at that time and to the previous values of both input and output functions. For example the component of cooling load at time t Q_t can be related to the corresponding component of the heat gain $q_{e,t}$ by the following equation (1) (Mitalas 1972):

$$Q_t = v_0 q_{e,t} + v_1 q_{e,t-\Delta} + v_2 q_{e,t-2\Delta} + \cdots = w_1 Q_{t-\Delta} - w_2 Q_{t-2\Delta} - \cdots \quad (1)$$

Where v and w are coefficients depend on the heat storage characteristics of the cooling zone and on the nature of the particular heat gain $q_{e,t}$. Thus each heat gain will be considered and the total cooling load Q will be calculated for each building as a function of time. Then peak coincident load will be reported which will be the cooling load required to serve the required buildings. This peak coincident load will be compared with the total TR of each split system to determine which is more energy saving.

3 Case study

3.1 District cooling plant location selection

The plant location selection is a strategic decision since it is a long-term one and will affect the other university surrounding premises. In addition, the location should be economical as much as possible to minimize the friction loss and consequently the annual electric consumption of the primary pumps. The selection of the plant must be apart from the buildings which include academic activities in order not to disturb the educational process with the machine noise. However, the district cooling plant walls will be isolated and the machines will be supplied with dampers to diminish noise emission. The part of the university campus which are studied are the first main seven buildings (A-H) and the following is the main university campus, figure (1).

Fig. 1. British university in Egypt main campus. From left to right: Buildings E, C, D

The two locations which are suitable for construction and fulfilling the above mentioned criteria are near the admission building (Bld E) and the other is between buildings A&G. The following figure (2) is summarizing the system layout for the two locations proposed. The location which will be selected must minimize the friction loss in the supply and return pipes.

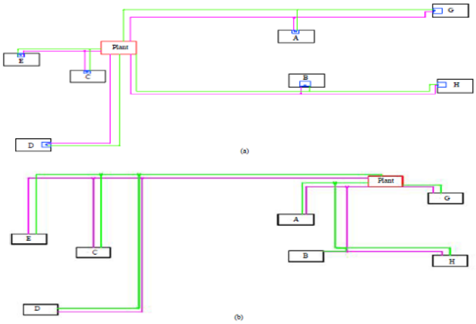

Fig. 2. District cooling system schematic layout for the two locations selected: (a) near building E and (b) between buildings A&G ; where the red box is representing the district cooling plant, black boxes for the serviced buildings, purple lines for supply chilled water pipes and green lines for the return chilled water pipes. The blue lines in (a) is for the thermal bridge reprsentation at each building where heat transfer occurs between the primary and secondary chilled water systems

The flow in the piping system is in parallel form and thus the longest path of chilled water flow will be representing the total pump head and power required. Regarding the first plant location which is near to the admission building (E), the longest path from the district cooling plant to a building was to building H and thus the total length of the supply section is determined to be $166.81\ m$, the flow rate required for building H to satisfy the cooling load is $222.34\ gpm$. Then using this information and the chart in reference (Carrier 2010), the pipe diameter and the friction loss per 100 ft of pipe can be calculated. However, the minor losses have to be considered; for each supply section there are 3 elbows and a T section which will cause minor pressure losses along the flow. The friction loss coefficient could be determined from tables in reference (Cengel 2010). The elbows are chosen to be of 90° smooth bend flanged type and thus K and the corresponding friction loss can be estimated. The T section for this pipe line is not in the flow path and thus the Tee (line flow) configuration will be selected with a flange and the friction loss will hence be calculated similarly to the previous calculations. The total friction loss for the supply piping can be calculated from this equation (5) (Cengel 2010).

$$h_{total} = h_{main} + h_{elbow} + h_{Tee-ine\ flow} \quad (5)$$

Where:
h_{total}: Total friction loss in the piping system
h_{main}: Main losses in pipe without its fittings and connections

The friction loss for the second proposed location would be calculated using the same algorithm and set of equations; the longest path is determined to be until building D and the required flow rate for this building is $405.9\ GPM$. In addition, there are 2 smooth end elbows and a T section, however in this case it is in the flow direction.

By comparing the system friction loss for each location, the first location which is near to building E has less friction loss than the second location by about 38.3% and thus the first proposed location from the point of view of friction loss and pump head is more economical to use and select. The following table (1) will be summarizing the friction losses for each proposed building for clarification

Table 1. Friction loss for each system at the two proposed locations

Friction loss type	1st location loss	2nd location loss
h_{elbow}	$0.164\ ft$	$0.11\ ft$
h_{Tee}	$0.11\ ft$	$0.558\ ft$
h_{main}	$19.12\ ft$	$26.53\ ft$
h_{total}	$19.75\ ft$	$27.83\ ft$
h_{system}	$39.05\ ft$	$54.61\ ft$

3.2 District cooling load

By establishing a district cooling plant including the chillers, primary and secondary pumps and cooling towers, thus would reduce the thermal load and the electrical consumption significantly. The maximum cooling load for each zone will be calculated and then the highest maximum point will be the system operating point. At this point the corresponding load for each zone will be considered to determine the total system cooling load, and hence this point is called the peak coincident point. This will reduce the cooling load significantly, rather than just summing up the individual maximum load for each zone. The following figure (3) will be summarizing the cooling load for the installed system and the district cooling system.

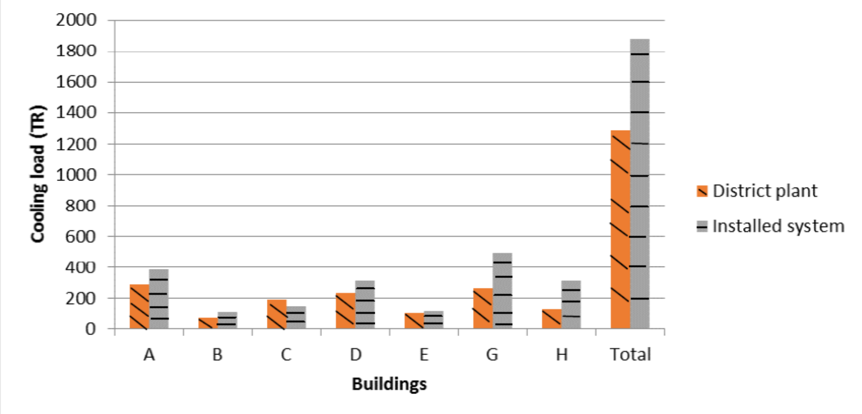

Fig. 3. Cooling load comparison at the BUE premises for the designed district system and the current installed system respectively.

3.3 Chiller selection

The total load (1284.6 tons), will be distributed over three centrifugal chillers, each chiller will be (430 tons).

The following tables (2&3) will be summarizing aspects of the selected chiller.

Table 2. Selected chiller aspects

Type	York water-cooled centrifugal liquid chiller
Refrigerant	R134a
Model	YKE3EPQ65EKG (380/3/50)
Cost of three units	Cost of three units: 510,000 USD

Table 3. Unit Data of the chiller

Unit Data	Evaporator	Condenser
EWT (°F):	54	85
LWT (°F):	41	95
Flow Rate (gpm):	791	1206
Pressure Drop (FT):	24.1	18.3
Fluid Type (%):	Water	Water
Circuit No. Of Passes:	3	2
Fouling Factor (ft^2°F hr/Btu):	0.00010	0.00025
Number of Tubes:	376	260
Working Pressure (psig):	150	150

3.4 Hydraulic study

The sample of calculations will be made for a pipe section in building D as showed in figure (4). The average flow velocity in pipes is recommended according to Carrier design manual to be $6.004\ ft/s$, the chilled water density is taken to be $62.43\ Ib/ft^3$ and the dynamic viscosity for a chilled water at 41°F is defined to be $1.02 \times 10^{-3}\ Ib/ft.s$. The pipe diameter can be calculated from the following equation (6) (Cengel 2010).

$$Q = A\ v_{avg} \quad (6)$$

Where:

Q: Volume flow rate

A: Pipe area

Thus the diameter of the pipe (D_{pipe}) is calculated to be

$$D_{pipe} = 0.0254\ m\ (1\ in.)$$

Hence, Reynolds number is calculated to be

$$R_e = 30600$$

Since, it is larger than 4300 thus the flow is turbulent and the friction coefficient (f) could be calculated from moody chart (Cengel 2010). In order to define the friction factor in the moody chart, the surface roughness coefficient is selected to be $0.0018\ in.$, it is selected from the surface roughness table as showed by Cengel et.al. (Cengel 2010).

Hence, the friction coefficient (f) is calculated to be 0.03 and thus the friction loss head in this pipe section is $h_L = 4.13\ ft$. Regarding the calculations from the Carrier pipe design manual, the friction loss in ft of water per 100 ft of pipe is 20

and thus the total friction loss will be $h_L = 4.16\ ft$. Since that the two values agrees to a great extent, thus the calculation from the chart in the manual would be reliable to continue with throughout the piping calculations.

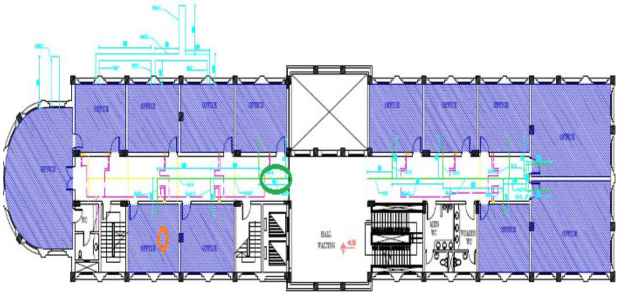

Fig. 4. Autocad drawing for first floor of building D showing the supply pipes and ducts connections. The orange circle represents the zone with longest pipes path and the green circle represents the pipe section for sample of calculations.

3.5 Piping configuration

The chilled water is collected at a header from the district plant, then it starts to be distributed to each secondary circuit at each building, where heat transfer occurs at a thermal bridge. The thermal bridge has a maximum length of 2 ft in order to cause significant friction loss so that the two streams of chilled water of the primary and secondary circuits do not mix with each other. The return system is chosen to be of reverse return type as showed in figure (5) (Carrier 2010)

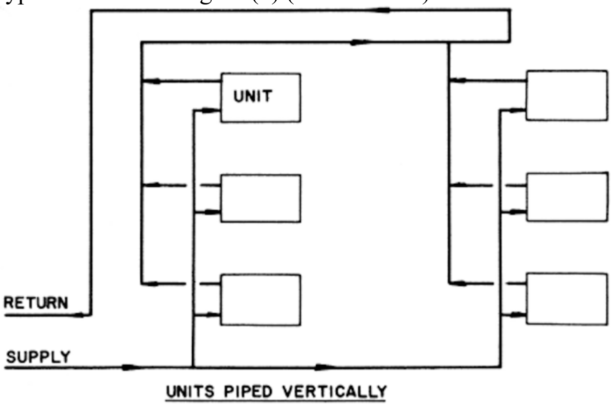

Fig. 5. Reverse return configuration (Carrier 2010)

The reverse return is aimed to eliminate balancing as the length of piping through the supply and return piping is the same. In addition, this will facilitate the design calculations since the friction loss across the two piping systems will not vary significantly. The following figure (6) is an example for the return concept applied to the primary circuit.

Fig. 6. Part of the supply and return pipelines for the primary circuit across buildings; where the purple lines are for the supply and the green line are for the return. And the blue lines are for the thermal bridge.

4 Energy Analysis and discussion

This section aims to study the monthly energy consumption of various system configurations in order to decide the best practice to operate the district cooling system. The system composes of three centrifugal chillers each of $430\ TR$, however the number of operating hours for the three chillers needed to be determined to decide the most convenient operating hours per day. Thus, the optimum hours of operation per day will be decided within this section to minimize the monthly electric consumption and hence the system running cost. The energy simulations are done through HAP software with $0.45\ EGP/Kwh$ as a simple constant electric rate, the operating hours are changed via thermostat settings. The operating hours per day are varied from $8-24\ hrs$ and the electric consumption for each case is plotted in figure (8)

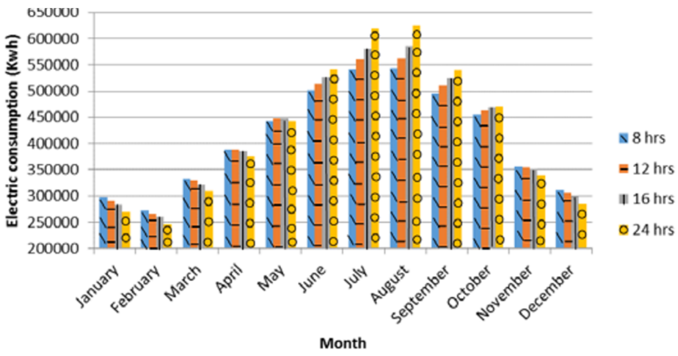

Fig. 7. Monthly electric consumption of the district cooling system at 8, 12, 16 and 24 hours per day respectively.

Figure (8) shows that starting from November up to May the 24 hrs of operation seems to provide the minimum energy consumption, however starting from June up to October the 8 hrs operation is the optimum operating configuration. Hence, there is no specific operating configuration, which will provide the minimum consumption throughout all the months, however the technical operator has to vary the operating hours based on the above chart. The 12&16 hrs of operation seem to intermediate values throughout the months; where the 16 hrs seem to be more economic than the 12 hrs in the months where the 24 hrs of operation preferred and vice versa for the months where the 8 hrs of operation excel.

5 Cost analysis

5.1 Running cost of the installed and proposed systems

The district cooling within this cost analysis is selected to operate at 8 hours per day for simplicity as there is no optimum operating hours and it must be changed from month to another as showed in the energy simulation section 4. The district system shows vast reduction in the running cost as the total annual costs reduced by 1,548,644 EGP. Note that the running cost of the DX system is not representing the actual cost as these costs are based on the recommended cooling load emerged from the manual and HAP calculations. The reduction per month is showed in figure (9).

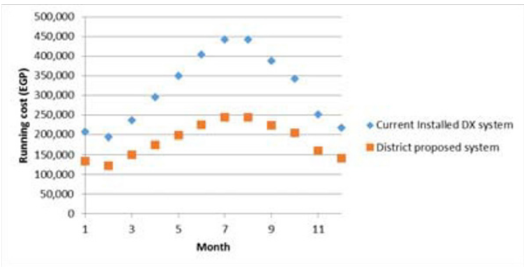

Fig. 8. Monthly running cost of the installed and the district proposed system

5.2 Payback period

The period where the cumulative savings as a result form the district cooling implementation will compensate the extra initial cost of the proposed system will be calculated. By comparing the current installed and district cooling proposed system, the net cash flow will be as showed in figure (10)

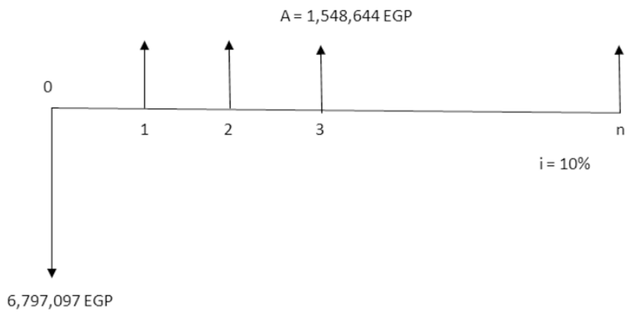

Fig. 10 Net cash flow for the installed and proposed system at interest rate = 10%

The present value is representing the difference between the initial costs of the two systems. In addition, the annual costs (A) are representing the savings in the running cost per year. The present value can be calculated from the compound interest rate tables (Jewkes 2009) and table (5) is showing the details of the calculation. Since that, the first non negative value occurs at year 7, thus the payback period of the project is at year 7. Note, at 0% interest rate, the payback (PB) period can simply be calculated to be $PB = \frac{6797097}{1548644} = 4.39 \sim 5$. However, the effect of the interest rate must be considered to have a realistic study. Moreover, the payback period of the actual system as pointed out will be less than 7 years since that there will be extra savings per year.

Table 5 Showing the accumulated cash flow calculations

year	Interest rate factor (P/F,i,n)	Accumulated cash flow at Present value (P) EGP
1	0.9091	-5389238
2	0.8264	-4109367.744
3	0.7513	-2945848.6
4	0.6830	-1888103.896
5	0.6209	-926517.81
6	0.5645	-52348
7	0.5132	742350

6 Results

Using the proposed district cooling system over the current installed DX system will reduce the kwh and thus the annual running costs by about 41%. Thus the annual costs according to HAP calculations using a simple constant electric rate, it will be reduced from 3.77 million EGP to 2.22 million EGP. An in terms of kwh it will be reduced from 8,377 Mwh to 4,933 Mwh. Regarding the cooling load consumption, it will cause 32% reduction as it will drop from 1882.3 TR to 1284.6 TR. Thus, using the district cooling with the peak coincident load concept will be significantly effective in reducing the costs and cooling load required by the cooling systems electric equipment.

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Part III
Advanced Mechanical Technologies

Review of fault detection techniques for health monitoring of helicopter gearbox

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Abstract. In most cases the helicopter transmission system comprises of the main gearbox (MGB), auxiliary gearbox (AGB), intermediate gearbox (IGB) and tail rotor gearbox (TGB). A local gear fault will impose a force variation in the gearbox and changes the gear angular velocity resulting in frequency modulations, which in turn generates sidebands and changes the vibration signature. The change in vibration signature contains information about the health of the gearbox from which diagnosis can be made to prevent the catastrophic effect of propagated fault. The helicopter gearbox vibration mode differs from those of other systems due to the transmission noise, structural noise and aero acoustic noise which masks the sideband. Thus an attempt is made to review the condition indicators that have been applied for fault diagnosis on the helicopter gearbox. This review is intended to advance the knowledge and the performance of Health and Usage Monitoring System in the helicopter transmission system.

Keywords: Helicopter; transmission; gearbox; vibration; fault detection; condition indicators; health monitoring

1 Introduction

Onboard sensors for helicopter health and usage monitoring systems (HUMS) have been in use since eighties with increasing popularity for improved safety and condition based maintenance, and was certified in November 1991 for operation in the North Sea [Greaves,2014; Pipe, 2003]. Several HUMS technology have since emerged comprising of onboard system for data acquisition and storage and a ground based system for data analysis, fault detection with diagnostic and prognostic capabilities for effective maintenance management.

Vibration Health Monitoring (VHM) integrated into Health and Usage Monitoring System (HUMS) has been useful for identifying the presence of defective gear tooth within the helicopter gearbox before it become catastrophic. This practice aids

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condition based maintenance and improved safety of helicopter operations among other benefits [Draper, 2003; Milsom *et al*., 2003; Augustine, 2004; Qu *et al*., 2014].

The VHM-HUMS systems acquire composite vibration data through accelerometers strategically placed, tachometer signals and contextual parameters such as airspeed, temperature and torque [Alattas and Basaleem, 2007; Lebold *et al*., 2000; Samuel and Pines, 2003]. The system predicts gearbox health in terms of a single number, called a condition indicator (CI), representing the condition of the monitored gearbox. The CIs are then compared with pre-set threshold values, established based on historical data, to offer an indication of fault progression within the gearbox, thus providing a basis to assess the health of the gearbox for further diagnosis [Rzeszucinski *et al*., 2012; Keller and Grabill, 2003].

In this paper a review of various vibration techniques used in HUMS and HUMS technology for fault detection and diagnosis on helicopter transmission systems is presented and their potentials for fault detection and diagnostics capabilities is highlighted.

Nomenclature	
TSA	time synchronous averaging
x	vibration signal after TSA
$R_{1,-1}(x)$	amplitude of the first order left hand side sideband
$R_{1,+1}(x)$	amplitude of the first order right hand side sideband
RMS	root mean square
NA4	ratio of the kurtosis of the data record divided by the square of the average variance
$NA4^*$	normalized kurtosis of the data record divided by the squared variance of signals
E	enveloped of the band-passed signal
$\bar{E}$	mean value of the envelop signal
N	total number of data points in time record
M	current time record number in the run ensemble
D	difference signal
$\bar{d}$	mean value of difference signal
i	data point number in time record

M6	sixth statistical moment
$\tilde{M}$	variance of the residual signal
r	residual signal
$\bar{r}$	mean value of residual signal
j	time record number in run ensemble
S	raw time series signal
$\bar{S}$	mean value of the raw time series signal
$(S-\bar{S})^2$	variance of the data set
$S_{0\text{-}pk}$	peak level of the raw time series signal
FM4	the ratio of the fourth statistical moment to the square of the variance of the difference signal
M6	the sixth statistical moment
NB4	the ratio of the fourth statistical moment of the envelope signal to the averaged variance of the envelope signal, raised to the second power

2 Time domain analysis (TDA)

Simple signal metrics applied to the measured time domain signal can give some information regarding potential defects. However, they are insensitive tools for defect detection and cannot be used to diagnose defects [Wandel, 2006] but can be useful as pre-processing techniques for metrics in other domains [Keller and Grabill, 2003]. The time domain techniques can be categorize into statistical parameters, time synchronous averaging based method and filter based methods.

2.1 Statistical Parameters

1. Root mean square (RMS)

The RMS represents the energy of the signal representing a sequence of n discrete values and indicates the amount of energy in the non-meshing components. It is useful in tracking the overall noise level to detect a major out-of-balance, but it will not provide any information on which component is failing and may not show appreciable changes in the early stages of damage [Figo et al., 2010; Wiig, 2006].

It is mathematically expressed as:

$$\text{RMS} = \sqrt{\frac{1}{n}\{\sum_{i=1}^{N}[S_i]^2\}} \quad (1)$$

2. Crest factor

The crest factor (CF) is described as a simple measure of detecting changes in the signal pattern due to impulsive vibration sources. Peaks in the time series signal will result in an increase in the crest factor value. However, the crest factor feature is not considered a very sensitive technique [Decker and Lewcki, 2003].

$$\text{CF} = \frac{S_{0-pk}}{\text{RMS}} \quad (2)$$

3. Kurtosis

The Kurtosis (K) is the fourth statistical moment of an array of values and an indicator of the existence of major peaks in a set of data. However, the pitfall with the normalized kurtosis parameter is its drastic decrease in peak sensitivity as the number N of peaks of similar magnitudes increase beyond two. It is derived by normalizing the square of the variance of the signal [Alattas and Basaleem, 2007].

$$\text{KURTOSIS} = \frac{N\sum_{i=1}^{N}(S-\bar{S})^4}{\left[\sum_{i=1}^{N}(S-\bar{S})^2\right]^2} \quad (3)$$

2.2 Time synchronous averaging (TSA) based methods

In this group we have the time synchronous averaged (TSA) signal, residual signal (RES), and difference signal (DIFS)

1. Time synchronous average signal

This method employed the repetitive signals after TSA to indicate faults which need to be diagnosed. A discontinuous time synchronous averaging (DTSA) method has been proposed [Huff *et al.*, 2003] to minimize torque and related non-stationary effects on the frequency content of transmission vibration signals using flight vibration data.

2. Residual signal

The RES which is developed to detect the onset of damage and monitor the fault development as it propagates and progresses, comprises of the NA4 and NA4*. The NA4 is the ratio of the kurtosis of the data record divided by the square of the average variance, while the NA4* is evaluated by normalizing the kurtosis for a data record by the squared variance of signals from a healthy gearbox [Hongyu *et al.*, 2003]. They are mathematically expressed as:

$$NA4 = \frac{N\sum(r_i - \bar{r})^4}{\frac{1}{M}\sum_j\left[\sum_i(r_{ij} - \bar{r}_j)^2\right]^2} \quad (4)$$

$$NA4^* = \frac{\frac{1}{N}\sum_{i=1}^{N}(r_i - \bar{r})^4}{(\tilde{M}_2)^2} \quad (5)$$

3. The difference signal

The difference signal estimates the difference signal by removing the regular meshing components from the time synchronous averaged signal comprises of FM4, M6A, and M8A [Rzeszucinski *et al*., 2012; Decker and Lewcki, 2003]. The FM4 is evaluated by dividing the fourth statistical moment about the mean by the square of the variance of the difference which magnifies any abnormalities present in the difference signal, while the M6 metric is a continuation of the kurtosis and the sixth statistical moment normalized by raising the power of the variance to the third power. They are mathematically expressed as:

$$FM4 = \frac{N\sum_{i=1}^{N}(d_i - \bar{d})^4}{\left[\sum_{i=1}^{N}(d_i - \bar{d})^2\right]^2} \quad (6)$$

$$M6 = \frac{N^2\sum_{i=1}^{N}(d - \bar{d})^6}{\left[\sum_{i=1}^{N}(d - \bar{d})^2\right]^3} \quad (7)$$

$$M8A = \frac{N^3\sum_{i=1}^{N}(d - \bar{d})^8}{\left[\sum_{i=1}^{N}(d - \bar{d})^2\right]^4} \quad (8)$$

Other TDA are the FM4* and M6* developed to overcome the limitations of FM4 and M6.

2.3 Filter based methods

Filter based methods include demodulation, Prony model, band-pass method and adaptive noise cancelling (ANC) used for removing noise and isolating signals [Hongyu *et al*., 2003].

The NB4 metric, a band-passed method is described as the time-averaged kurtosis of the envelope of the signal band-passed filtered about the mesh frequency [Lebold *et al*., 2000], obtained by dividing the fourth statistical moment of the envelope signal by the current run time averaged variance of the envelope signal, raised to the second power. NB4* was developed to overcome the limitation of the NB4.

$$NB4 = \frac{N\sum_{i=1}^{N}(E_i - \bar{E})^4}{\left\{\frac{1}{m}\sum_{j=1}^{m}\left[\sum_{i=1}^{N}(E_{ij} - \bar{E}_j)^2\right]\right\}^2} \quad (9)$$

Sideband level factor (SLF) is another TDA technique and described as the sum of the first order sideband levels about the primary gear meshing frequency normalized by the RMS of the synchronous time averaged signal [Nacib *et al.*, 2013]. It is mathematically expressed as:

$$\mathrm{SLF} = \frac{\mathrm{FOSL}}{\mathrm{RMS}} = \frac{R_{L-1}(x) + R_{L+1}(x)}{\mathrm{RMS}(x)}. \tag{10}$$

The energy ratio (ER) is also a TDA technique which compares the residual energy and the meshing energy by dividing the RMS of the difference signal with the RMS of the regular components of the signal [Wiig, 2006]. It is expressed as:

$$\mathrm{ER} = \frac{\mathrm{RMS}_d}{\mathrm{RMS}_r} \tag{11}$$

The root mean square, crest factor, energy operator, energy ratio, kurtosis, M6, FM4, NA4, NA4*,NB4, NB4*, M6*, FM4*, FM0, N6A, N8A, M6A and M8A to the vibration data of OH-58 helicopter main transmission [Decker and Lewicki, 2003; Lewicki *et al.*, 2011; Mosher *et al.*, 2003]. Modified FM0, Sideband level factor, energy ratio, sideband index, kurtosis, FM4 for monitoring planetary gears fault have been developed to detect planetary carrier fault of UH-60A helicopter [Keller and Grabill, 2003].

3 Frequency domain analysis (FDA)

The FDA techniques reveals the repetitive nature of a signal to indicate faults in a time-signal of a specific window using the discrete Fourier transform [Hongyu *et al.*, 2003], by making comparison of a measured spectrum to a reference spectrum of a healthy component to expose faults at different frequencies in the spectrum. These techniques are based on the assumptions of stationary vibration signals, however, for a complicated gearbox, the frequency spectrum is complex and is characterized by non-stationary transient components [Wandel, 2006], thus rendering ineffective this approach, coupled with the small energy of the signal and high level of noise [Klepka, 2011].

3.1 Fast fourier transform (FFT)

The FFT represent the average signal, dominant frequency components and other important characteristics of a time-based signal in the frequency domain. Though it is useful in identifying harmonic signals, however due to its constant time and frequency resolution, it is weak in analyzing transient signal components [Lokesha *et al.*, 2011].

3.2 Cyclostationarity

Cyclostationarity uses spectral correlation function to investigate the correlation degree between different frequency components of the spectrum and establish their relationship with each other [Li *et al*., 1996] for the early diagnosis of faults in gear systems

3.3 The power cepstrum

The power cestrum is useful for detection of sideband periodicities in a complicated vibration frequency spectrum which can be related to a defect. However, it is difficult to predict absolute sideband levels from the cepstrum [Wandel, 2006].

The cepstrum analysis and the spectrum analysis have been applied to helicopter gearbox diagnosis [Nacib *et al*., 2013]. The spectra analysis, the power spectrum analysis and amplitude demodulation was applied to the swash plate bearing of a CH-47D helicopter [Keller and Grabill, 2003]. The averaged harmonic ratio, non-regular meshing ratio was applied to epicyclic gearbox of a UH-60A Blackhawk Helicopter [Wu and Vachtsevanos, 2003]. Though the techniques indicate the progression of crack growth in a planetary gear plate it is however, based on linear correlation

4 Joint-time frequency domain analysis (JTFDA)

The time domain and frequency domain techniques are based on the assumptions of stationary vibration signals [Klepka, 2011], however, localized gear defects introduces non-stationary transient signal components in the meshing vibration that may excite structural resonances of the gearbox. A time-frequency distribution captures the time-varying frequency content so that changes in the amplitude of the signal could be analyzed in three dimensions of time, frequency and amplitude [Wang and Wong, 2000; Christian et al., 2007], and capable of tracking the development of the faults, which generate weak vibration power [Lakis, 2007], but requires complex computational analysis.

Examples in this domain are:

4.1 Short time fourier transform (STFT)

The STFT based techniques breaks down non-stationary signal into small windows, which is assumed stationary. However, this method suffered from resolution trade-off between time and frequency [Wandell, 2006].

4.2 The wigner ville distribution (WVD)

The WVD a bilinear function which is independent of the window function for excellent resolution in the time and frequency domains for a non-stationary signal. WVD has been employed on helicopter spiral bevel in a test rig at NASA Lewis Research Centre [Choy *et al*., 1996]. However, WVD is not always non-negative and prone to interference which makes it confusing and difficult to interpret.

4.3 The wavelet transform

The wavelet transform based techniques employs a family of window functions of variable lengths to study how the frequency content changes with time for localizing faults in vibration signals with non-stationary, transient characteristics [Farokhzad et al., 2013]. Short time Fourier transform (STFT), the wigner-ville distribution with the Choi-Williams kernel, the continuous wavelet transform (CWT) and the discrete wavelet transform (DWT) was applied to helicopter spiral bevel gear and pinion pair in a test rig [Mosher *et al.*, 2003].

5 Other diagnostic techniques

Other diagnostics approach employed on the helicopter transmission not listed in the categories above are constrained adaptive lifting, probability density function, finite element formulation, principal component analysis and planet separation method. The constrained adaptive lifting (CAL) was applied to vibration data of a planetary gear [Samuel and Pines, 2003], though it shows potential for transmission diagnostics but it is limited to laboratory work. Likewise, the Amplitude probability Density Function (APDF) applied to a spiral bevel gear of helicopter drive train [Rzeszucinski *et al.*, 2012], however fault detection is delayed and fault indication is very small and may not be useful for field applications. A finite element formulation was applied to the spiral-bevel gear and the planetary gear of a helicopter transmission [Stringer *et al.*, 2009]. Though the technique demonstrates the potential of physics-based mathematical models, the model itself requires further development and testing. Planet separation method and planet carrier method was applied to epicyclic gear train of a helicopter [Blunt and Keller, 2006] which prove to be reliable under test-cell conditions but less effective under low torque on-aircraft conditions. Likewise, Principal Components Analysis (PCA) was applied to helicopter flight data [Turner and Huff, 2001], which demonstrate the potential to monitor changes in the vibration, but suffers from assumption of linearity of combination of the three axes of measurements and insufficient testing. Amplitude and phase modulations techniques has been applied to helicopter transmissions in a test rig [Krishnappa, 1997], though the techniques are effective for early gear fault detection, however limited data is used and required prior knowledge of the baseline condition of the gear. Harmonic index and intra-revolution energy variance was also tested on vibration data of planetary gears [Wu *et al.*, 2005], with potentials to identify faults, however no experiments was carried out and further investigation is required.

Unsupervised pattern recognition has also been employed to detect abnormality in the vibration features. Single category based classifier was applied to a helicopter gearbox [Jammu *et al.*, 1996] to detect abnormality scaling of the vibration features. The United Kingdom Civil Aviation Authority (CAA) in conjunction with Eurocopter and General Electric (GE) has also employed the advanced anomaly detection, an unsupervised learning approach based on data mining to define models of normal behaviour and abnormal behaviour.

The Integrated Mechanical Diagnostics Health and Usage Management Systems (IMDHUMS), the Generic Health and Usage Management Systems (GenHUMS) and Vibration Management Enhancement Program (VMEP) are commercial HUMS technologies which have demonstrated potentials for fault diagnosis and condition based monitoring. The Federal Aviation Administrator (FAA) and CAA have developed techniques to process vibration data and determine condition and health indicators used in commercial HUMS [Dempsey *et al.,* 2007]. Vibration Management Enhancement Program (VMEP) a data collection and processing test-bed for the continuing collection and analysis of large amounts of data in support of vibration monitoring, automated diagnostic and prognostic system development have also been developed by the US Army and Air force. The VMEP system has been employed on UH-60A Main Transmission Planetary Carrier to acquire and analyze on-aircraft data and test cell data [Keller and Grabill, 2003; Blunt and Keller, 2006; Grabill *et al.,* 2003]. IMDHUMS perform data acquisition, analysis, display and storage with maintenance management functions to mechanical diagnostics and operational usage [Hess *et al*., 2003]. The technology has being fielded on a number of helicopters with significant detection [Wright, 2005].

Multivariate statistical approach applied to Helicopter Integrated Diagnostic System (HIDS) developed by Naval Air Warfare Center in a seeded fault tests, produced clear fault detection with a reduced number of false alarms [Mimnagh, 2000]. A joint research of FAA and Army Aviation Engineering Directorate on Army helicopter fleet Health and Usage Monitoring Systems (HUMS) for Condition Based Maintenance (CBM) focuses on data analysis and development of component health and usage indicators for estimation of remaining useful life of dynamic and structural parts [Zion *et al*., 2016].

6 Conclusion

Vibration Health Monitoring (VHM) integrated into Health and Usage Monitoring System (HUMS) has contributed immensely to the reliability condition based maintenance of the helicopter transmission systems. Some of the conventional condition indicators generally used on the helicopter transmission system were discussed. Other diagnostics and prognostics methods and systems that have been developed were also discussed. It is important to document these techniques in order to advance the knowledge and the performance of Health and Usage Monitoring System in the helicopter transmission system.

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Internet of Things – A Predictive Maintenance Tool for General Machinery, Petrochemicals and Water Treatment

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Abstract. Improper and unnecessary maintenance actions can result in a waste of resources, time, and money. Training and education play an important role in the successful implementation of a maintenance strategy. The Center for Predictive Maintenance (CPM) at the University of South Carolina has developed a demonstration methodology and tool that can be used to educate and train users extending from maintainers to leadership on the maintenance process from fault to maintenance action. This overall methodology has been developed so that it can be applied to a variety of industries including general machinery, petroleum and petro chemicals, and water treatment. All of these industries have a need for successful implementation of predictive maintenance programs and this demonstration methodology can be used to train and educate users. This demonstration tool will walk an audience through the maintenance process starting with the collection of sensor and historical data. Then it will show the analysis of the data through modeling and statistical analysis techniques. Finally, the data and results are displayed in unique dashboards that provide personnel with the information needed to make educated decisions on the condition and maintenance of their system.

Keywords**:** Predictive maintenance, Internet of Things;

1 Introduction

Traditionally, the two most common strategies for maintenance management were either reactive or preventive. Reactive maintenance is a failure-based strategy where maintenance actions are performed only after the component has failed. Preventive maintenance is a time-based or usage-based strategy where maintenance actions are performed after a set amount of time. Both types of strategies have their strengths

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and weaknesses. Reactive maintenance can save money in the short-term, but long-term can lead to higher repair costs and longer down-times. Preventive maintenance results in higher reliability but can be more costly if maintenance is performed before it is actually needed.

In order to achieve both high reliability and low cost, a predictive maintenance strategy would need to be implemented. Predictive maintenance is condition-based and maintenance is performed only when the component requires it. Predictive maintenance also allows for predictions to be made on when a component will fail which allows maintainers to be prepared for that failure before it happens. Implementing predictive maintenance can provide a company with an optimal maintenance strategy at a low cost with the highest reliability.

2 Background

Maintenance is a large part of any industry and depending on the industry can represent between 15 and 60 percent of total costs. In the United States, industries spend more than $200 billion each year on maintenance. Recent surveys have shown that there is a need for better maintenance implementation. Improper and unnecessary maintenance actions make up almost 33% of maintenance costs [Mobley, 2002].

A successful implementation of predictive maintenance can result in many benefits including reduced maintenance costs, increased readiness and availability, and increased feelings of safety. In order to achieve these benefits, predictive maintenance requires new processes and technologies. This is where training and education become important in the success of a predictive maintenance strategy. If maintainers and other users are not properly trained on the different processes of predictive maintenance then the results of cost-savings and high reliability will not be seen.

The Center for Predictive Maintenance has developed an Internet of Things (IoT) based methodology for creating a demonstration that can be used to train and educate users on predictive maintenance. This methodology can be applied to various industries such as general machinery, petroleum and petro chemicals, and water treatment. Even though these industries involve differing maintenance needs and procedures, the same IoT methodology for predictive maintenance can be applied.

3 Internet of Things

The Internet of Things (IoT) refers to a network of interconnected objects or things [Atzori et al, 2010]. These objects are able to communicate and interact with each other regardless of physical location. In the maintenance world, these objects are embedded with sensors that monitor the condition of the object. Over the years, the IoT has increased in popularity in maintenance. It provides a framework for users to connect and collect data from all the components and systems that they are monitoring. This data is collected and analyzed in real time to identify and extract meaningful relationships in the data. The collected data can also be compared to previous trends that were calculated with historical data. In the IoT framework, not only are the physical components and systems connected, but also every user in the maintenance process is connected. This means that a user does not need to be physically with the asset to know its condition. The information a user would need is presented to them with real-time dashboards and alerts.

The IoT has changed the way users think about data. If an IoT framework is being implemented, then there is a large amount of data is continuously being collected in real-time from the network of sensors. This data being collected from the components and systems is full of valuable insights and useful relationships but it also presents some difficulties. One problem is how to manage and extract value from the IoT data. Previously, data could be stored locally but this approach has its limits on storage and efficiency. In order to quickly store, manage, and analyze IoT data, cloud computing will need to be used.

Cloud computing uses a network of servers hosted on the internet to store, manage, and analyze data as opposed to doing it locally on one machine. This setup allows resources such as computing power and storage to be shared across the network of servers providing a large capacity for storage and processing power. The cloud framework can be divided into different areas that include cloud storage, cloud applications, and cloud infrastructure as shown in Figure 1. The cloud storage contains databases for the collected and processed data. Cloud applications include programs that a user might need access to. This includes programs for analyzing the data, creating diagnostic and prognostic models, generating reports and work-orders, and real-time dashboards containing information. The cloud infrastructure refers to the setup of the network. Having the data and programs stored in the cloud allows a user with the proper credentials access no matter where they are located. There is also the benefit that they can view the results and data from any device because the programs are not located locally on their machine but instead in the cloud.

Cloud computing addresses the problem of storing and managing the IoT data but it doesn't solve the problem of how to analyze the data. This is where the research area of big data analytic fits in. Big data is a term used to describe large amounts of data sets that can be analyzed for extracting patterns, trends, and relationships. There are large amounts of data associated and generated from maintenance. Data directly related to the condition of a component or system can be historical or current (real-time). Historical data includes logistical data from maintenance records which can also include a user's experience and knowledge. Historical data also includes previously collected sensor data. Current data includes the data being collected from the sensors. Other types of data that might impact the condition of a component or system can also be collected such as the weather or environmental variables. Data and knowledge from technical manuals and reports also have value. In order to extract useful information from all this data, advanced analytic techniques for big data will need to be used.

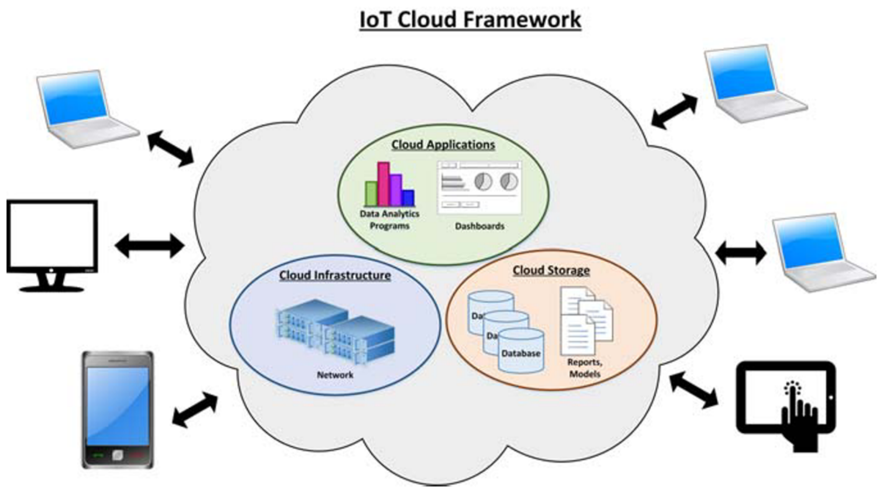

Figure 1: Internet of Things cloud framework.

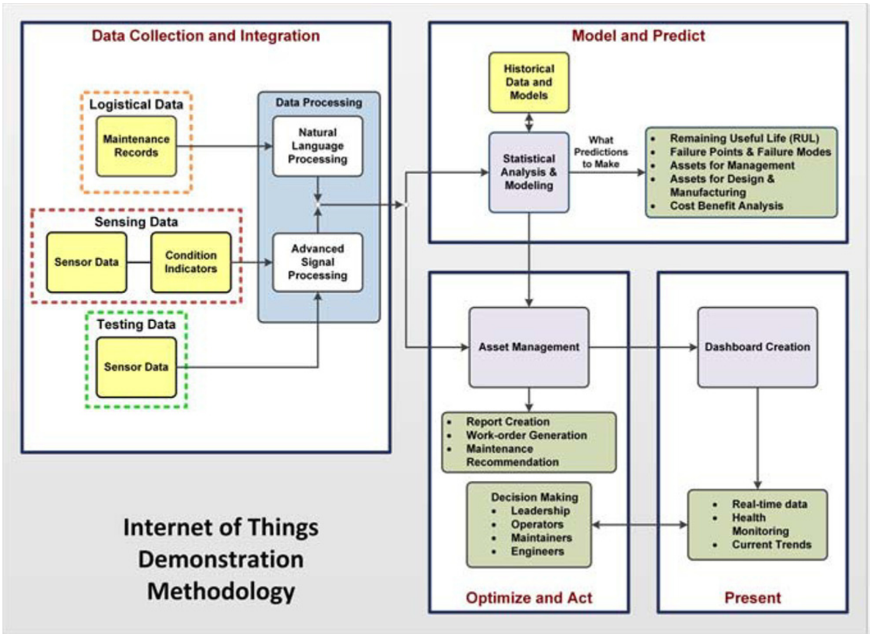

Figure 2: Internet of Things demonstration methodology

4 Methodology

Predictive maintenance is a system's level approach that can be broken down into four areas: data collection and integration, model and predict, optimize and act, and present. The developed methodology creates a demonstration that addresses those four areas. Figure 2 shows the demonstration methodology. The goal of the demonstration is to allow a user to see the whole process from start to finish.

4.1 Data Collection and Integration

Data collection is a very important step in predictive maintenance and data can come in three different types: logistical, sensing, and testing. Logistical data contains information on the maintenance actions performed on a component or system. Sensing data is collected from sensors on the component or system. The last type of data is testing data, this is collected sensor data from a test stand that can be used to validate and refine models and relationships found in the logistical and sensing data. After collection, the data will need to be processed before it can be stored or analysed. Written text from logistical data can often contain mistakes and gaps due to human error. Techniques such as natural language processing will need to be done in order to transform the text into a useable form [Bokinsky et al., 2013]. The collected sensor data will be processed using techniques such as advanced signal processing. Advanced signal processing helps in the extraction of relationships between sensors [Coats et al., 2011].

Data integration will then be done to combine the different types of data into one set. Combined, the data can give a more complete picture than one set could on their own.

4.2 Model and Predict

After the data has been collected and processed, it can be analysed through models and predictions. Data can be used to address many different questions depending on what the user's goals are and what predictions they want to make. For example, if the user is interested in information about the life of the component or system they are monitoring then diagnostic and prognostic models can be created to show information such as remaining useful life. In order to create diagnostic and prognostic models, historical data would be used to create an initial model for detecting failures. The current real-time data would compared against those models to see if a failure exists. The current data is also stored and later used to refine the initial fault models. Other predictions can include models for cost-benefit analysis, failure points and failure modes, and design and manufacturing.

4.3 Optimize and Act

The next step involves asset management. After the data has been used to create models and predictions, the results of these models will need to be interpreted. This step results in the creation of reports, generation of work-orders, and recommendation of maintenance actions. The types of users that would be using these results for decision-making include leadership, operators, maintainers, and engineers.

4.4 Present

The final step is to present the data and results in the form of a dashboard. These dashboards are created to be tailored to fit the needs of the user so that they only view the information important to them. These dashboards allow a user to view data in real-time, look at current trends, and monitor the health of a system.

5 Applications to Industry

The IoT methodology can be used to develop predictive maintenance tools for the advancement of predictive maintenance in industries such as general machinery, petroleum and petro chemicals, and water treatment. Even though these industries involve differing maintenance needs, the same IoT methodology for predictive maintenance can be applied to all of them. It is important to advance the maintenance practices of these industries because they play a vital role in our lives. In the area of general machinery, components have usually been repaired on a time-based schedule which leads to unnecessary maintenance repairs and increase in maintenance costs. The petro chemicals industry is facing large growth and with that a need for efficient maintenance practices. One important area of the water resource industry is the desalinization of water. In order to keep the cost of desalinization down, unscheduled maintenance needs to decrease. Predictive maintenance can address all of these problems and lead to a reduction in unscheduled and unnecessary maintenance.

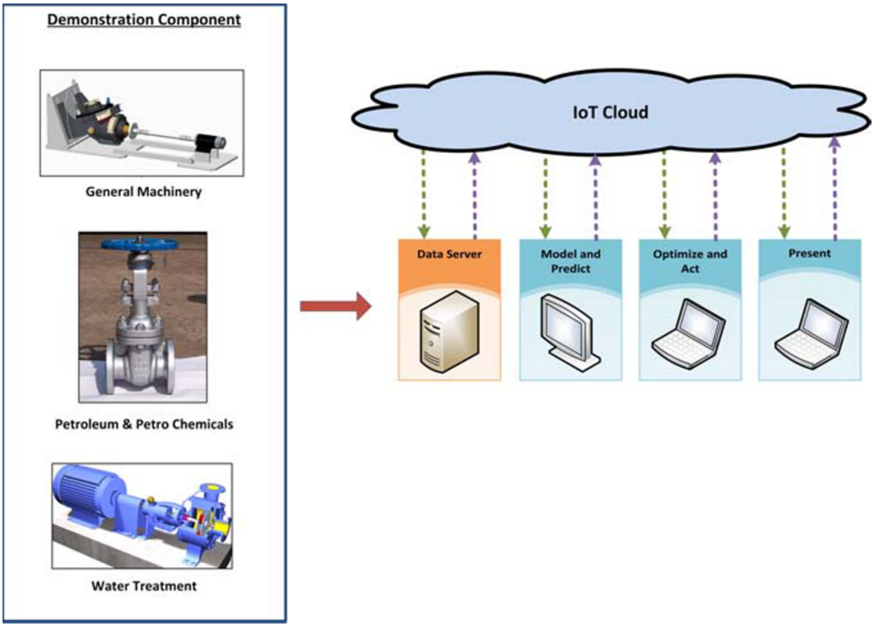

Figure 3: Internet of Things demonstration setup for various industries using different components.

5.1 General Machinery

Industries related to general machinery include aviation, aerospace, steel industries, paper industries, and other heavy industries. These industries have a lot of maintenance issues related to gears, bearings, shafts, and structure. Previously, these industries have relied on a preventive maintenance strategy based on time. Due to this, maintenance is one of the largest cost drives in these industries with maintenance representing up to 60% of total costs [Mobley, 2002]. Implementing predictive maintenance would help to reduce these costs by decreasing the amount of unnecessary repairs. A demonstration for predictive maintenance in general machinery has been created using a gearbox, shown in Figure 3 [Edwards et al., 2016]. Rotating components are heavily used in general machinery, and a gearbox is a good example.

5.2 Petroleum and Petro Chemicals

Industries related to this area include energy, gas, oil, and nuclear. The products of this industry provide many of the needed materials for our daily lives from propane to nuclear energy. This area is also experiencing a large growth and with that an increase in maintenance needs. Implementing predictive maintenance can help to address the maintenance issues this industry will face while reducing cost. Two problematic areas in this industry are control valves and process automation. A demonstration related to this industry could be built around a control valve, shown in Figure 3. The control valve would be fitted with various types of sensors. The goal of this demonstration would be to train and educate users on new monitoring techniques and how they could benefit their company. Similar to the demonstration for general machinery, there will be three screens for the user to view during the demonstration. The user will be able to see on the screens how different monitoring techniques can improve the data collected and provide more accurate models.

5.3 Water Treatment

The desalination and purification of water is becoming a more pressing issue as the human population increases and water resources decrease. Water desalination has the potential to be a solution to water shortage problems, but currently it is a very expensive process. Establishing a predictive maintenance program can help to reduce some of these costs by reducing unnecessary downtimes and increasing reliability and availability. For this demonstration, a pump will be used to demonstrate predictive maintenance, shown in Figure 3. Sensors will be used to monitor pressure, temperature, and motor amperage. The goal of this demonstration will be to show how predictive maintenance can ensure that unscheduled maintenance is not a part of the high cost of water desalination. This demonstration would be similar to the setup of the general machinery demonstration.

5.4 Results

The gearbox demonstration for general machinery has already been implemented by the Center for Predictive Maintenance. Demonstrations for other industries would be very similar with just the component being monitored changing. The gearbox is fitted with various sensors to collect data for temperature and vibration. Data collection software would then be used to transfer the sensor data to be stored in a database where historical data has already been processed. During the demonstration, users will see three screens. The first represents the “data collection and integration” step. The users will see how the data looks coming off the gearbox and visualize any trends. The “model and predict” step is not visible to users by itself because it’s mostly calculations, but the user can get an understanding of this step by observing what happens before and after this step. The “model and predict” step will take in the data being collected and run it against created fault models. The output of this step will be visible in the next screen which shows the output of the models. The second screen represents the “optimize and act” step and will display work-order generation based on the results from the predictive models. The last screen represents the “present” step and displays a dashboard that shows the real-time condition of the gearbox. The demonstration is designed to allow faults to be introduced.

Figure 4 shows example screenshots of what the audience sees during the demonstration. The top row represents views during normal operating conditions. In screen one the audience can see the values for different sensor readings. During normal operating conditions nothing unusual is noted. The data is continuously being compared against the fault models and outputs the results to screen two. Since there is no fault being detected, the bottom portion of the work order is empty. Screen three represents a real-time dashboard that shows the user the health condition of the gearbox. The health condition reads normal since there is no fault. The bottom row represents what an audience sees when there is a fault detected. During the demonstration, a fault will be introduced. In this example it is a thermal fault. In screen one, the audience will see the temperature readings start to rise compared to when the gearbox was running normally. The fault models will now detect that there is a thermal fault based off of the new data. Screen two will then create a work order based on a thermal fault and the bottom section will be filled out with instructions. Screen three will also be updated and the dashboard will show the health condition as being critical, alerting the user that something is wrong. This setup allows the audience to watch all three screens change as the condition of the component changes.

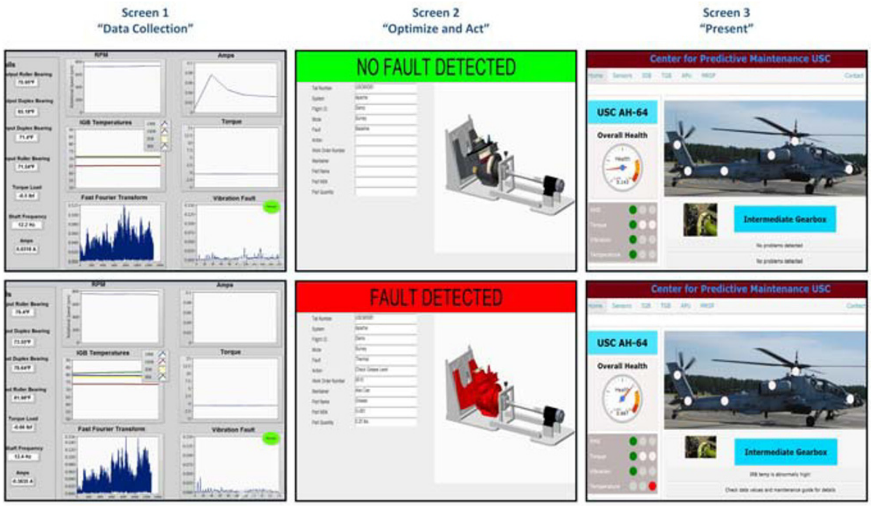

Figure 4: Screenshots of what the audience sees during the demonstration.

6 Conclusions

With the advancement of technologies such as big data analytics and cloud computing, IoT has continued to grow and change the way users collect, view, and analyse data. Using an IoT approach in maintenance can help industries move to predictive maintenance which is the optimal maintenance strategy. Predictive maintenance relies heavily on data, and IoT provides the best methodology for analysing data and connecting all users. The demonstrations previously outlined are built on an IoT methodology for predictive maintenance that can be applied to any industry's maintenance needs.

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Mechanical fault detection and classification using pattern recognition based on bispectrum algorithm

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Abstract. Higher order spectral analysis of vibration signals is an efficient tool in condition monitoring and fault detection and diagnosis of rotating machinery. In this paper, features extracted from vibration bispectrum are used in fault classification of critical rotating components in the AH-64D helicopter tail rotor drive train system. Different classifiers are used to compare the performance of the proposed algorithm based on bispectrum to the traditional algorithms based on linear auto- and cross-power spectral analysis techniques. Principal component analysis (PCA) is used to reduce the size of features extracted from vibration bispectrum and linear spectral analysis, then the reduced set is used to train different classifiers. Using different criteria such as accuracy, precision, sensitivity, F score, true alarm, and error classification accuracy (ECA), the performance of the proposed algorithm is evaluated and compared against similar classification algorithms. The proposed method is verified using real-world data collected from a dedicated AH-64D helicopter drive-train research test bed at the CPM center, University of South Carolina. The proposed algorithm increases the accuracy of fault detection to 96.88%, precession to 95.83%, sensitivity to 95.83%.

Keywords: Vibration Analysis; Bispectrum; Condition Based Maintenance; Machine Learning; Principle Component Analysis; Logistic Regression; Rotating Machinery Fault Detection

1 Introduction

Condition based maintenance (CBM) is a maintenance program that uses information collected through continuous condition monitoring of systems to recommend maintenance decisions [1]. CBM has proven to be more reliable, accurate and efficient than traditional time based maintenance (TBM) which depends on changing

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parts after working for finite number of operational hours or finite period of time. CBM is more important for rotorcraft as there are a lot of critical component that experience high dynamic load and their maintenance after failure needs high cost. More important than cost is the safety of all people on the rotorcraft. P. D. Samuel in [2] discussed the cost of failure of rotorcraft and summary of accident count and their reasons.

One of the CBM objectives is to discover and classify errors in high asset value mechanical systems such as the AH-64D tail rotor drive system. Failure of such a system may lead to serious helicopter accidents and loss of lives. CBM consists of three steps: First, sensor data are acquired to collect information about the mechanical system under study (e.g., vibration signal as in [3] and acoustic signal as in [4]). After data acquisition, collected data is processed to extract indicative features which are correlated to the system's health. Many signal processing techniques can be used such as time domain analysis discussed in [5], frequency domain analysis including power spectrum and bispectrum [6], time frequency analysis [7] and wavelet analysis [4]. Third step in CBM is the fault detection and diagnosis using machine learning algorithms such as pattern recognition in order to map features into faults. Different studies have been conducted to extract condition indicators (CI) for fault detection. For example,spectral peak 2 (SP2) has been used as a CI to detect drive shafts' misalignment and/or imbalance [5]. However, this CI has limited diagnostic capabilities where it doesn't specify fault type. CIs based on higher order spectral analysis, such as quadratic coupling index A_{QC} based on cross bispectrum [6] and quadratic nonlinearity power index QNLPI based on normalized bicoherence[8], have shown higher performance in terms of distinguishing different fault cases. However, using higher order spectral analysis needs more experience and human efforts in order to correctly interpret results and categorize fault cases.

In this paper, based on vibration bispectral analysis, a fully automated fault detection and classification algorithm is proposed and used to distinguish three common drive-shaft faults in the AH-64D tail rotor drive train, namely;shaft misalignment, shaft imbalance, and a combined case of shaft misalignment and imbalance from a baseline healthy case. The proposed algorithm uses features extracted from both auto- and cross- bispectrum. The extracted features are then filtered using principle component analysis (PCA) to reduce the burden on the pattern recognition algorithm. Using real-world vibration data, different classification algorithms are compared against each other to get the highest performance using a set of criteria including accuracy, precision, sensitivity, F score, true alarm and error classification accuracy (ECA). Classification algorithms used in this study are naïve bayes, linear discrimint analysis, quadratic discrimint analysis, support vector machine, multiclass logistic regression

This paper is organized as follows: First, mathematical foundation to calculate auto and cross power spectrum and bispectrum is introduced in section 2. Experiment setup and vibration data collection and organization are discussed in section 3. Section 4 introduces the steps of the proposed classification algorithm. In section 5, evaluation criteria to compare the proposed algorithm based on bispectral analysis to its power spectral analysis counterpart are discussed. Section 6 presents the results of the study, and section 7 is the conclusion.

Nomenclature	
AHB	aft hanger bearing
CBM	condition based maintenance
CI	condition indicator
FHB	forward hanger bearing
PCA	principle component analysis
SVM	support vector machine
HOS	higher order statistical analysis
LOI	loss of information
CM	confusion matrix
ECA	error classification accuracy

2 Theoretical foundation of bispectral analysis

Information in the vibration signals collected from rotating mechanical components can be extracted and interpreted using differentsignal processing concepts. One of the fundamental concepts is the auto correlation function $R_{xx}(\tau)$which is defended for a wide-sense stationary signal$x(t)$ as:

$$R_{xx}(\tau) = x(t) \star x(t) = \int_{-\infty}^{\infty} x^*(t)x(t+\tau)dt \tag{1}$$

where ($\star$) is the correlation operator and ($*$) is the complex conjugate of the signal. Auto correlation measures statistical dependence between signal $x(t)$ and a time shifted version of it, $x(t+\tau)$, which in turn reveals information about any periodicity in the signal.Cross correlation function, on the other hand, measures the statistical dependence between a signal $x(t)$ and a shifted version of another signal $y(t+\tau)$, and can be calculated using equation (2).

$$R_{yx}(\tau) = x(t) \star y(t) = \int_{-\infty}^{\infty} x^*(t)y(t+\tau)dt \tag{2}$$

Since it is impossible from the experimental point of view to have access to all realizations of $x(t)$and $y(t)$,the auto and cross correlation are estimated statistically from a finite number of realizations as described in equations (3) and (4).

$$R_{xx}(\tau) = E\{x^*(t)x(t+\tau)\} \tag{3}$$

$$R_{xy}(\tau) = E\{x^*(t)y(t+\tau)\} \tag{4}$$

where E{.} is the expected function operator.

The Wiener-Khinchin theorem [9] states that auto-power spectrum $P_{xx}(f)$ is the Fourier transform of the auto correlation function $R_{xx}(\tau)$and the cross-power spectrum $C_{yx}(f)$is the Fourier transform of cross correlation function $R_{xy}(\tau)$ and they can be estimated using equations (5) and (6) respectively.

$$P_{xx}(f) = E\{X^*(f)X(f)\} = E\{|X(f)^2|\} \tag{5}$$

$$C_{yx}(f) = E\{X^*(f)Y(f)\} \tag{6}$$

wheres signal$X(f)$ is the Fourier transform of the signal $x(t)$ which can be calculated by the following equation:

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt \tag{7}$$

Bispectrum is the Fourier transform of the third order correlation functionR_{xxx}. It is a very powerful technique to detect nonlinearities in the signals. It detects and quantifies frequency componentswhich result from nonlinear physical phenomena by using phase coupling.If two frequency components are cross-interacted together due to some nonlinearity, two new frequency components will be generated at the sum and the difference values of the interacting frequencies, and the resulted components will be phase coupled to the interacting frequency[6][10].

Third order auto correlation function$R_{xxx}(\tau_1, \tau_2)$and third order cross correlation can be estimatedusing equations(8) and (9) respectively.

$$R_{xxx}(\tau_1, \tau_2) = E\{x^*(t)x(t+\tau_1)x(t+\tau_2)\} \tag{8}$$

$$R_{xxy}(\tau_1, \tau_2) = E\{y^*(t)x(t+\tau_1)x(t+\tau_2)\} \tag{9}$$

The auto bispectrum is the Fourier transform of the auto correlation functionR_{xxx}which describes frequency components resulted from nonlinear relation between two frequency components in the same signal. While the cross bispectrum is the Fourier transform of the cross correlation signal R_{xxy} and it describesfrequency components in a signal *Y(f)* that resulted from nonlinear relation between two frequency components in the signal *X(f)*.Equation (10) is used to estimate auto bispectrum while equation (11) is used to estimate cross bispectrum.

$$B_{xxx}(f_1, f_2) = E\{X(f_1)X(f_2)X^*(f_3 = f_1 + f_2)\} \tag{10}$$

$$S_{xxy}(f_1, f_2) = E\{X(f_1)X(f_2)Y^*(f_3 = f_1 + f_2)\} \tag{11}$$

3 Experimental data description

Data used in this study are collected using two accelerometer sensors located at the forward hanger bearing (FHB) and the aft hanger bearing (AHB) of an Apache AH-64D helicopter experimental tail rotor drive system as shown in Fig. 1[6]. The two sensors collect vibration signal simultaneously every 2 minutes during 30 minutes experimental run. The experiment is repeated 16 times using four different hanger bearings with four serial numbers 0321, 0316, 0373 and 01ARL and the experiment is repeated four times for each hanger bearingto test different-shafts settings as follows: 1- base line case (balanced and aligned), 2- imbalanced and aligned, 3- balanced and misaligned, and 4- imbalanced and misaligned.

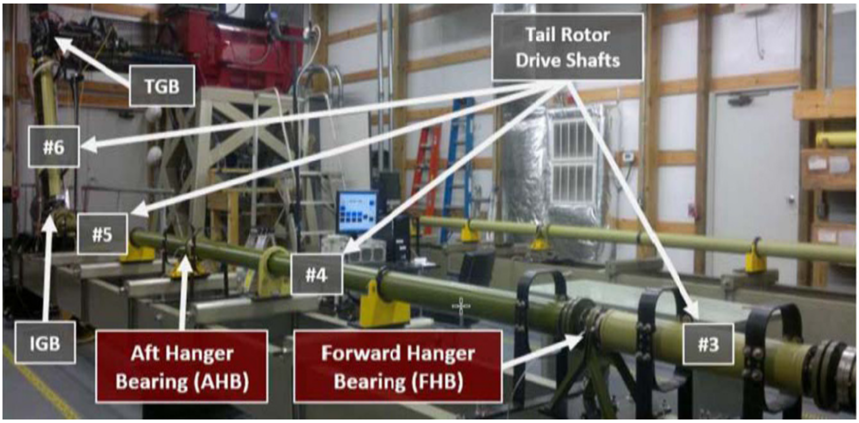


Fig. 1. Experiment helicopter tail rotor drive system with labelled drive shafts and indication for sensor places [3]

Each case of the four shaft settings is given a unique digit from 0 to 3 and this digit is added before the serial number of any hanger bearing to give a unique test-code for each shaft and hanger bearing case (e.g., for the test number 10321, first digit to the left, 1, indicates shaft condition and the remaining number indicates the bearing serial number).

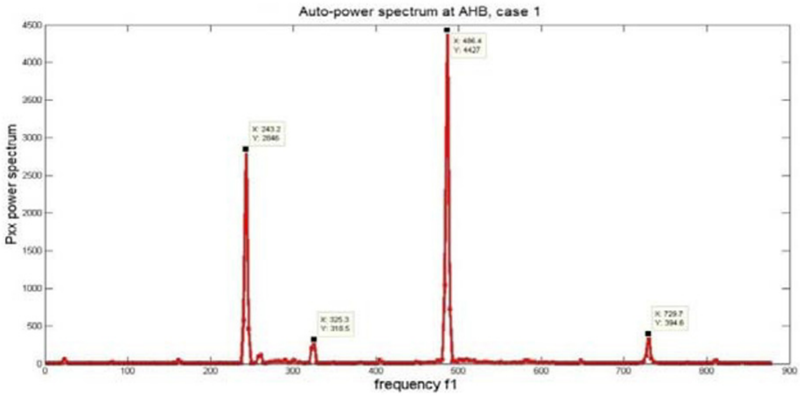
Each vibrationsegment has 65536 data points collected at sampling rate of 48 kHz (f_S) which results in data collection time of approximately 1.31 sec per acquisition.Vibration signals are collected during operation of the test stand at a constant rotational speed of 4863 rpm (81.05 Hz) from the prime mover. The input torque applied to the input of the shaft and hanger bearing is equal to 32.35 ft.lb, while the output torque is equal to 111 ft.lb which is the torque applied at the output of the tail rotor gearbox.

4 Proposed classification algorithm

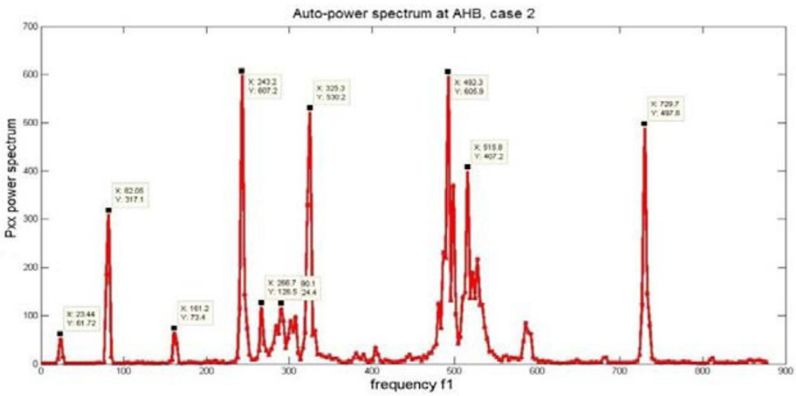
This section discusses how features are extracted from power spectrum and bispectrum, how PCA is used to reduce features number and how multiclass logistic regression, which gives best results among all classifiers,can be used to classify features into correct classes.

4.1 Auto and cross power spectrum

For the vibration signals collectedat the AHB and FHB sensors,autocorrelation is first calculated for individual AHB and FHB signals, then the cross correlation between themisestimated using equations (5) and (6) given in section 2.Features extracted from power spectra are then fed directly to the PCA algorithm. In this subsection, some plots of vibration power spectra are presented in order to get the sense of the required human efforts to interpret the results. However, this step of plotting the result is not required.



(a)



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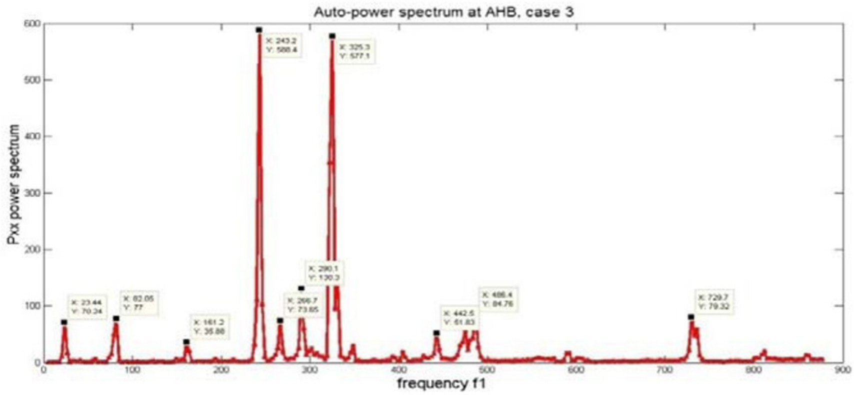

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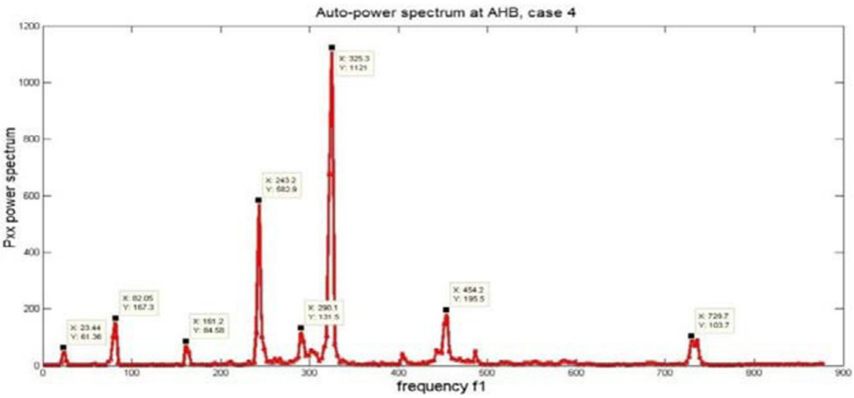


(d)

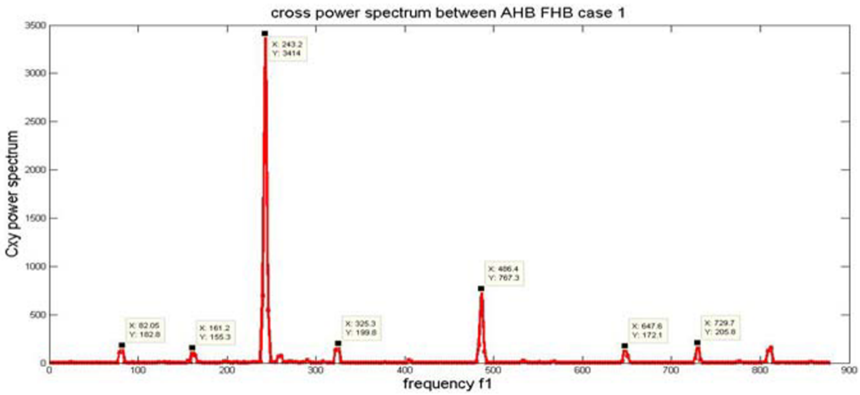
Fig. 2. (a) AHB auto power spectrum case 1; (b) AHB auto power spectrum case 2; (c) AHB auto power spectrum case 3; (d) AHB auto power spectrum case 4;

Figure 2 shows the auto power spectrum at the AHBand how vibration power is distributed at different frequencies especially at the fundamental frequency (81.05 Hz) and its harmonics 2R at (161.2 Hz), 3R at (243.2 Hz), 6R at (486.4 Hz). It can be notedthat at the healthy case most of the vibration power is located at 3R and 6R harmonics as shown in Fig. 2(a). However, in the second case (unbalanced and aligned shafts) the power distributed over a range of frequencies including 1R, 2R, 3R ,4R, and 9R as shown in Fig. 2(b). The third case (balanced and misaligned shafts) has vibration power which is distributed over the 3R and 4R harmonics as shown in Fig. 2(c). In the last case (unbalanced and misaligned shafts), most of the vibration power is located at 4R and there are small peaks at 1R,2R and 3R as shown in Fig. 2(d).

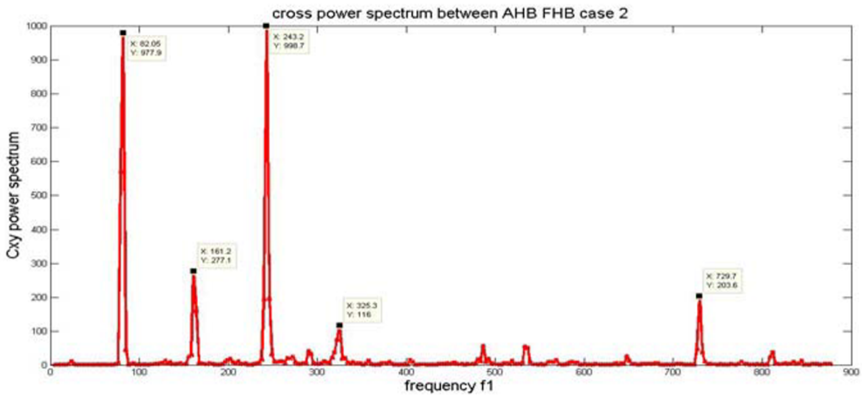
Cross power spectrum between AHB and FHB is also a very important tool to extract features that are important in distinguishing the four cases under study. Figure 3 shows the cross power spectrum variations between different cases.

The cross power spectrum between FHB and AHB has distinct vibration power distribution as in the case of auto power spectrum of the AHB discussed above.The healthy case shown in Fig. 3(a) has vibration peaks at 3R harmonic. Case 2 shown in Fig. 3(b)has vibration power distributed between the fundamental frequency and the third harmonic, while case 3 shown in Fig. 3(c) has power at 1R, 2R, and 3R. In the last case shown in Fig. 3(d), vibration power is distributed over 1R, 2R, 3R, 5R, and 9R.

To automate the process of fault classification, auto and cross power spectral data of the AHB, and FHB are used to extract features to be used for pattern recognition.An easy way to extract the feature set is to think about each frequency pin as an independent feature and feed the whole spectral contents to a classifier. However. The large number of frequency pins may lead to higher cost of computation in terms of resources and time. Therefore, principle component analysis PCA is suggested to be used in order to reduce the number of features to only 95 features as will be shown later in section 5.



(a)



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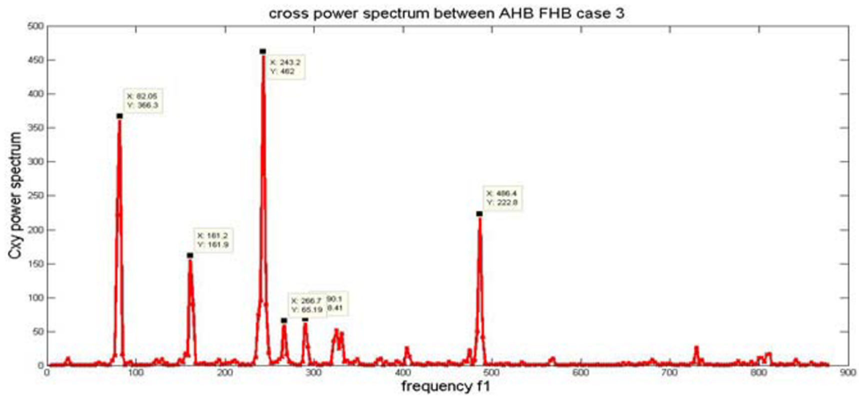
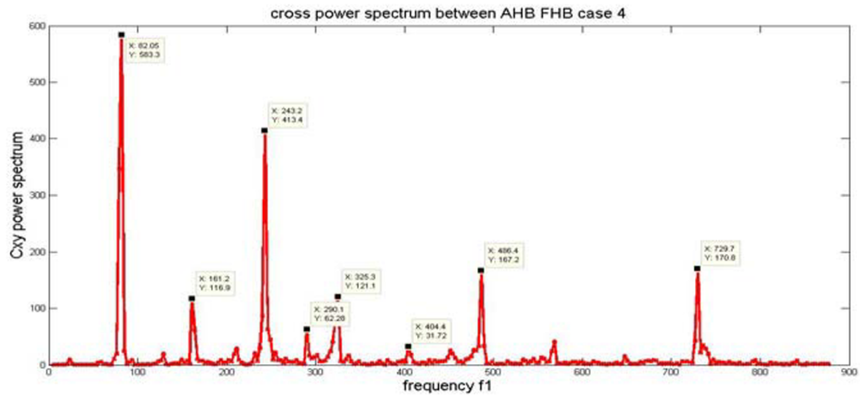


(c)



(d)

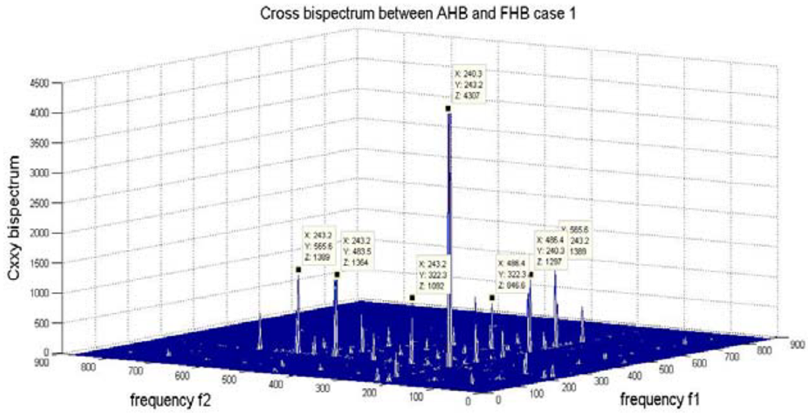
Fig. 3. (a) Cross power spectrum case 1; (b) Cross power spectrum case 2; (c) Cross power spectrum case 3; (d) Cross power spectrum case 4;

4.2 Auto and cross bispectrum

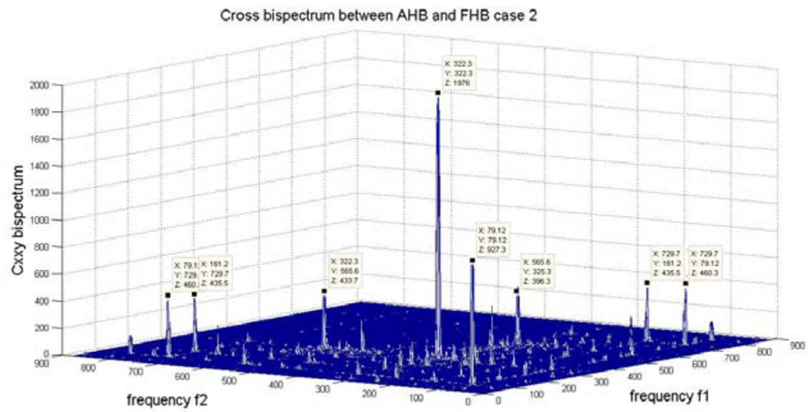
For feature extraction from bispectrum, auto bispectrum from the individual AHB and FHB signals are both estimated. Also, cross bispectrum between FHB and AHB and cross bispectrum between AHB and FHB are calculated. All the four measures are used to form the feature set which is then fed to the PCA algorithm. Again, although not required as part of the classification algorithm, some bispectral plots are discussed in this section to get a sense of its complexity and the effort needed to interpret it without applying the proposed automated classification algorithm.

Figure 4 shows the cross bispectrum between AHB, FHB in the four studied cases.As shown in Fig 4(a), nonlinear interactions at healthy case takes place between 3R with some other harmonics such as 3R, 6R, and 7R. However, in the second case (unbalanced shafts), nonlinearity appear between 4R with other harmonics such as 4R, 7R, and 9R and also between 1R and 1R as shown in Fig. 4(b). In the third case (misaligned shafts), nonlinear interactions occur between 3R with 1R, 3R, 4R, 5R as shown in Fig. 4(c). While in the last case (unbalanced and misaligned shafts), nonlinear interactions take place between 3R with 3Rand 1R and between 4R and 6R as shown in Fig. 4(d). Thus, different cases can be distinguished from each other by different characterizing nonlinear interactions patterns.

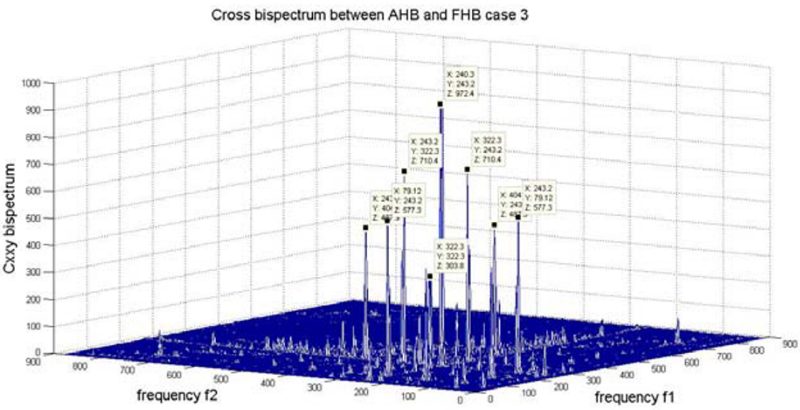
By taking the information from the bispectral analysis in to consideration and use features extracted from them in pattern recognition after applying PCA, the accuracy of the classification increases as will be discussed in section 5.



(a)



(b)



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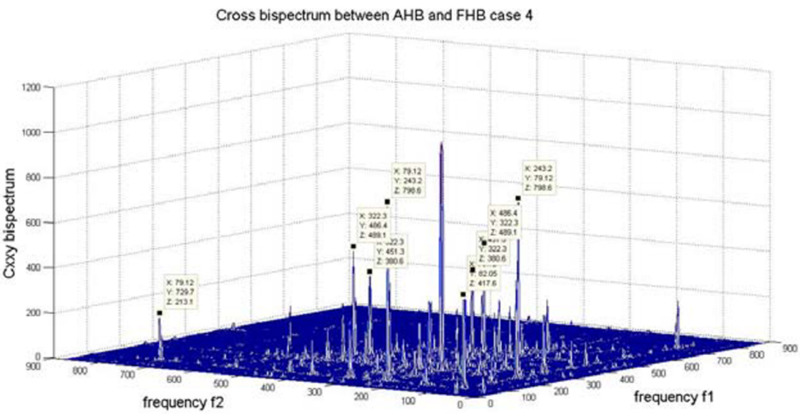

(d)

Fig. 4. (a) Cross bispectrum case 1; (b) cross bispectrum case 2; (c) cross bispectrum case 3; (d) cross bispectrum case 4;

4.3 Principle component analysis

PCA is a widely used technique for dimensionality reduction. It can be defined as the linear projection that minimizes the average projection cost, defined as mean squared distance between the data [11]. PCA works by finding a set of orthogonal components that minimizes the mean square error of the reconstructed data and represent the original data with fewer components, which reduces the dimension of the data [12]. Loss of information (LOI) can be calculated by finding the ratio between the eigenvalue (λ_i) of this feature and summation of eigenvalues as a result of the elimination of the element ith as indicated in equation (12) is the calculation of LOI. PCA components are ordered by largest variance.

$$LOI = \frac{\lambda_i}{\sum_{m=1}^{n} \lambda_m} \quad (12)$$

where *n* is length of feature set.

Reconstruction error in PCA is the average of the difference between the original matrix and the reconstructed matrix.

4.4 Multiclass logistic regression

In this study, multiclass logistic regression has the highest reliability and the best results among other classifier used, as will be shown later in section 6. Therefore, mathematical foundation of this pattern recognition algorithm is presented in this subsection.

Logistic regression is a discrete supervised learning algorithm that classifies multiclass problems by separating them into a number of binary class problems [11]. It converts the multiclass problem to binary class problems by taking every class against all the other classes. So, to classify data into four classes as in our case, logistic regression separates the problem into four binary problems.

a- Class 1 versus class 2,3,4

b- Class 2 versus class 1,3,4

c- Class 3 versus class 1,2,4

d- Class 4 versus class 1,2,3

Then for each sample, logistic regression train the hypothesis ($h_\theta^{(i)}(x)$) four times for each class i to predict the probability that (y=1) at this class and the class i that maximize the probability that $h_\theta^{(i)}(x) = 1$is considered as the class that the sample belongs to. So, if the largest hypothesis was at case c, the sample belongs to class 3. Equation (13) is used to calculate the hypothesis ($h_\theta(x)$) for every binary classification problemwhich depends on sigmoid function evaluated in equation (14). After hypothesis calculation, the cost function$J(\theta)$ is evaluated, as described in equation (15), which represents the averageerror between hypothesis and reality on all training samples. Finally, gradient descent algorithmis used to minimize the cost function and update the new values of theta parameters as shown in equation (16).

$$h_\theta(x) = g((\theta^T x)) \quad (13)$$

where *g (.)* is the sigmoid function equation (14),$(.)^T$ is the transpose of the matrix and *x* is the training samples features.

$$g(z) = \frac{1}{1+e^{-z}} \quad (14)$$

$$J(\theta) = -\frac{1}{m} \left(\sum_{i=1}^{m} (y^{(i)} \log\left(h_\theta(x^{(i)})\right) + (1 - y^{(i)}) \log\left(1 - h_\theta(x^{(i)})\right)\right) \quad (15)$$

where *m* is number of training samples$y^{(i)}$ is the real class of sample *i* of the training set, $x^{(i)}$is the features of the training sample *i*.

$$\theta_j := \theta_j - \alpha(\sum_{i=1}^{m}(h_\theta(x^{(i)}) - y^{(i)})x_j^{(i)}) \quad (16)$$

where θ_j is the parameter number j in the parameters vector, $(:=)$ means simultaneous update of all parameters, α is the learning rate, $x_j^{(i)}$ is the feature number j in the training sample number i.

Gradient descent is an optimization algorithm that updates the value of theta parameters in the direction that minimizes the cost function $J(\theta)$ iteratively.

5 Algorithm performance evaluation

In this section criteria used to evaluate the proposed algorithm are discussed. For power spectrum, 96 samples are collected to be used for training and testing different classifier, 24 samples for every shaft case of the four cases. And for bispectrum 128 samples are collected, with 32 samples for every study case. In power spectrum and bispectrum 70% of the samples are used as a training set and 30% as a testing set.

5.1 Fault detection evaluation criteria

In this subsection, the evaluation criteria used compare the performance of pattern recognition algorithms based on bispectrum against conventional power spectrum are introduced.Different classification algorithms are to conduct this study including naïve bayes, linear discrimint analysis, quadratic discrimint analysis, support vector machine, multiclass logistic regression and trained neural network.The criteria used in this comparison are accuracy, precision, sensitivity, F score, true alarm, and error classification accuracy (ECA). Those criteria are calculated using confusion matrix (CM)elements described in equation (17) [12].

$$CM = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{23} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \quad (17)$$

Every row in CM represent actual values and every column represent predicted values so S_{xy} represent valuesthat actually in class *x* and predicted by the classifier to be in class *y*. Recall that 1 is the healthy case 2 is the unbalanced case, 3 is the misaligned case and 4 is the unbalanced and misaligned case. The definitions of evaluation criteria parameter and how to calculate them are as follows:

1- Accuracy : a value express the degree of closeness between reality and classifier results, it is measured as the ratio of truly classified samples to the total number of samples

$$accuracy = \frac{S_{11}+S_{22}+S_{33}+S_{44}}{\sum_{i=1}^{4}\sum_{j=1}^{4} CM(i,j)} \quad (18)$$

2- Precision : a value that express the classifier ability to predict error correctly and it can be measured by the ratio between total number of samples that are*truly* classified as they contain error to the total number of samples that are classified as they contain error.

$$precision = \frac{S_{22}+S_{33}+S_{44}}{\sum_{i=1}^{4}(CM(2,i)+CM(3,i)+CM(4,i))} \quad (19)$$

3- Sensitivity: is the classifier ability to distinguish and classify error, it is calculated by the ratio between truly classified samples predicted to have error and the total number of samples that actually contain error.

$$sensitivity = \frac{S_{22}+S_{33}+S_{44}}{\sum_{i=1}^{4}(CM(i,2)+CM(i,3)+CM(i,4))} \quad (20)$$

4- F score : is the weighted average of precision and sensitivity

$$F\ score = \frac{2*precision*sensitivity}{precision+sensitivity} \quad (21)$$

5- True alarm:the ratio between number of times the classifier predicts error and there was actually an error.

$$true\ alarm = 1 - \frac{S_{12}+S_{13}+S_{14}}{\sum_{i=1}^{4}(CM(2,i)+CM(3,i)+CM(4,i))} \quad (22)$$

6- Error classification accuracy (ECA): a parameter that measures accuracy of classifying samples predicted to have errors and they actually have errors in the right class.

$$ECA = \frac{S_{22}+S_{33}+S_{44}}{\sum_{i=2}^{4}\sum_{j=2}^{4}CM(i,j)} \quad (23)$$

5.2 PCA feature selection

PCA algorithm is used to reduce the number of features extracted from power spectra from 4096 to 95 features. The number of principal components is less than or equal to the number of original samples [11] [13]. Therefore, PCA converts 4096 features to a number of features less than the number of samples which in our case 96 samples so we get 95 linearly uncorrelated features and every principle component contain some information as shown infigure 5which gives loss of information at every principle component we use all the features given from PCA so as to represent 100% of data information.

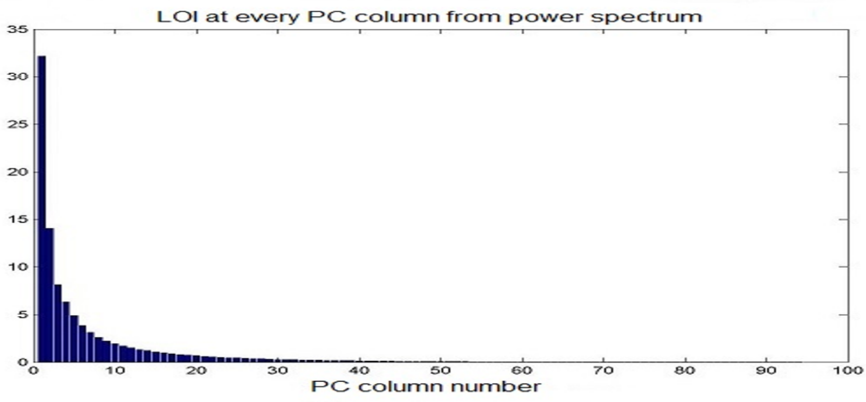

Fig. 5.PCA loss of information at every column of PCA featuresextracted from vibration power spectrum

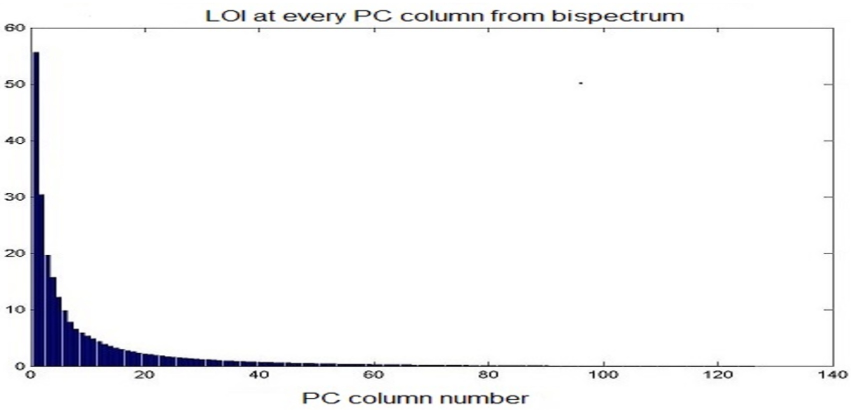

Fig. 6. PCA loss of information at every column of PCA features extracted from vibration bispectrum

Bispectrum has 360000 features which represents a burden on the pattern recognition algorithm. Therefore, PCA is used to reduce the number of features to a number less than or equal the samples which in this case is equal to 128 samples. PCA output in this case is 127 linearly uncorrelated features. In PCA, smaller eigenvalues of covariance matrix provide less pattern information [11]. Figure 6 shows the loss of information at every principle component of 127 components of the bispectrum.In this paper all the 127 features used in order not to lose any information.

6 Results

In this section, the results of training different classifiers using features extracted from both bispectrum and power spectrum are presented and compared using the evaluation criteria discussed above.

For pattern recognition based on feature extracted from power spectrum, the best classification performance is achieved when logistic regression and neural network are used. Figure 6 and table 1 show the results of evaluation for all classifiers.

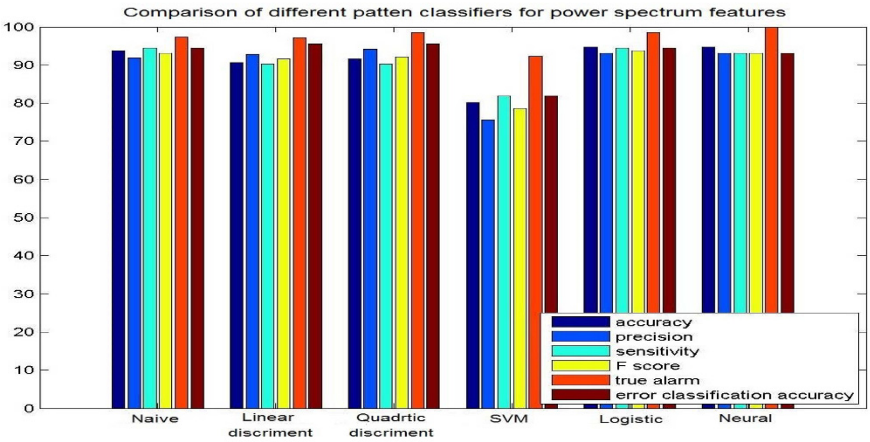

Fig. 7.Comparison of six pattern classifiers using features from power spectrum

Table 1. Comparison of different classifiers using features extracted from power spectrum

Pattern algorithms	Accuracy	Precision	sensitivity	F score	True alarm	ECA
Naïve bayes	93.750	91.89	94.44	93.15	97.29	94.44
Linear discrimint	90.62	92.85	90.27	91.54	97.14	95.58
Quadratic discrimint	91.67	94.20	90.28	92.20	98.55	95.59
Support vector machine	80.21	75.64	81.94	78.66	92.3	81.94
Logistic regression	94.79	93.15	94.44	93.79	98.63	94.44
Neural network	94.79	93.06	93.06	93.06	100	93.05

As indicated in Figure 6 and table 1, the best accuracy is achieved using neural network and logistic regression and it is equal to94.79 %. However, for precision and error classification accuracy, quadratic discrimint analysis gives best results, for sensitivity and F score, logistic regression shows better results than other and true alarm of the neural network has the best result of 100%. So, in summary, logistic regression shows best classification performance if power spectrum features are used.

Although bispectrum is more complex techniques than power spectrum and it has more features, using bispectrum features to train pattern recognition classifiers gives better results. Among different classifiers, logistic regression and neural network have the best accuracy, precision, sensitivity and ECA. Both of them also have 100% true alarm. Figure 7 and table 2 compare all classifiers using bispectrum features.

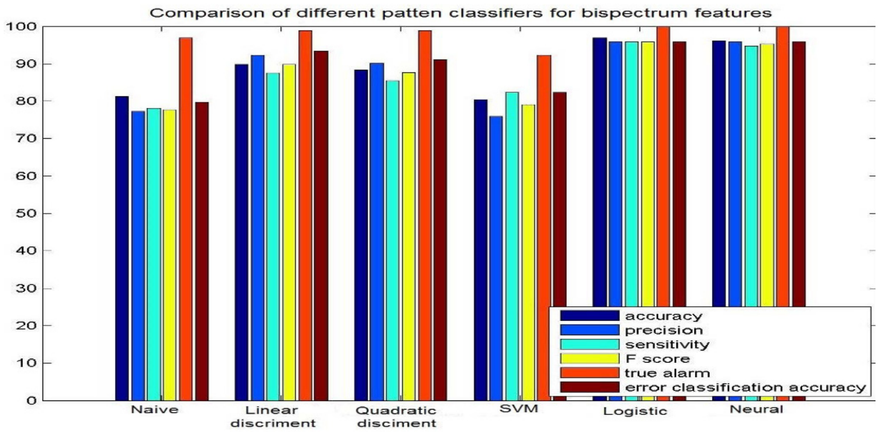

Fig. 8.Comparison of six pattern classifiers using features from bispectrum

Table 2. Comparison of different classifiers using features extracted from bispectrum

Pattern algorithms	Accuracy	Precision	sensitivity	F score	True alarm	ECA
Naïve bayes	81.25	77.32	78.13	77.72	96.91	79.79
Linear discrimint	89.84	92.31	87.50	89.84	98.90	93.33
Quadratic discrimint	88.28	90.11	85.42	87.70	98.90	91.11
Support vector machine	80.47	75.96	82.29	79	92.31	82.29
Logistic regression	96.88	95.83	95.83	95.83	100	95.83
Neural network	96.09	95.79	94.09	95.29	100	95.79

7 Conclusion

In this paper,fault detection and diagnosisof a rotating mechanical system have been improved by training a pattern recognition algorithm using features extracted from vibration bispectra. The proposed algorithm uses features extracted from both auto-and cross- bispectrum then reduce the feature set using principle component analysis (PCA). The proposed algorithm has shown the ability to detect 3 different mechanical faults (drive shaft imbalance, misalignment, and combined case of shaft imbalance and misalignment) and distinguish them from the healthy case and from each other.Six pattern recognition algorithms have been used to classify the data collected in this study from trail rotor drive train of an AH64D helicopter.A complete set of criteria has beenusedto evaluate theproposed algorithm including accuracy, precision, sensitivity and error classification accuracy (ECA). The proposed method has shownhigh performance in all of these criteria.Using features extracted from the conventional power spectrum, multiclass logistic regression and neural network have shown the highest classificationperformance with 94.79%accuracy, 93.15% precision, 94.44% sensitivity, and 94.44% ECA. When feature extracted from bispectrum is used, classification performance has recorded measurable increase such as 96.88% accuracy, 95.83%precision, 95.83%sensitivity, 100%true alarm and 95.83% ECA.The tradeoff of the proposed technique is its higher complexity and computational cost than linear power spectrum.

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Internet of Things – A Complete Solution for Aviation's Predictive Maintenance

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Abstract. The University of South Carolina has been involved in research for the US military for helicopters and rotary aircraft for over 18 years. Majority of this work has been focused on optimizing aircraft uptime and flight readiness by leveraging condition-based maintenance (CBM), more commonly known as predictive maintenance (PM). This type of maintenance differs from other classical styles (reactive and preventive) in that it has a high reliability and a low cost. The foundation of PM in any application is data collection and storage. It begins with applying tools such as natural language processing (NLP) to historical maintenance records to determine the most critical components on the aircraft. Data mining of previously collected sensor data is then used to establish the most reliable types of condition indicators (CIs) that monitor the critical components. These thresholds from the CIs can be modified over time as more data is collected. Once a data collection scheme is in place, prognostics can be used to determine the remaining useful life of a component. Using this process, along with an optimized maintenance schedule through the maintenance steering group (MSG-3) program, helps to eliminate unnecessary maintenance actions on the aircraft, as well as, reduce the inventory of components needed for the aircraft to operate. After this maintenance scheme has been set up, the Internet of Things (IoT) can be leveraged to allow the entire process to operate within a single environment. This further develops the solution, and allows actions to be executed more quickly than if they were performed individually. The expected benefits and future development of these practices will never come to fruition unless personnel are properly educated and trained. Developing a culture of predictive maintenance practices in an aviation environment is necessary to ensure success of this solution.

Keywords: Predictive Maintenance, Aerospace, Internet of Things, Asset Management, Prediction Algorithms, Natural Language Processing, Data Mining MSG-3, Aviation, Co ndition-Based Maintenance,

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1 Introduction

The Internet of Things (IoT) is the connection of any device to another entity with the ability to transfer data between one another. It has recently gained popularity due to the realization of the benefits that it can have while being used to monitor a multitude of devices, including expensive machinery, cars, and even our own activity levels. With this knowledge, it should come as no surprise that this technology is currently being implemented to enhance the current predictive maintenance (PM) practices of the Army aviation fleet to help reduce maintenance burden, prevent unnecessary maintenance actions, increase safety, increase system readiness, refine the maintenance process, and improve component design.

Traditional maintenance practices, like reactive (failure-based) and preventive (time-based), are becoming less popular due to the amount of overall cost associated with having to repair components that are either not broken, or have failed unexpectedly and are now costly due to unforeseen downtime. Optimized scheduled maintenance through the MSG-3 program allows the user to better understand the failure modes of component that is being monitored, however it still has untapped potential. PM has become a popular cost-effective alternative driven by the increased affordability of computing equipment and electronics. PM is a process in which tasks are performed on a component based on evidence of need, which integrates reliability, availability, and maintainability (RAM), reliability-centered maintenance (RCM), and CBM analyses. These processes, technologies, and capabilities enhance the readiness and maintenance effectiveness of systems and components. PM uses a systems engineering approach to collect data, enable analysis, and support the decision-making processes. Analysis and predictions include, but are not limited to, predicting remaining useful life (RUL), determining failure points, assessment of component design, materials behavior, tribological properties, and design and manufacturing properties (Edwards et al., 2016, Goodman et al., 2009, Goodman, 2011, Bayoumi et al., 2012, 2013).

2 Background

For nearly 20 years the University of South Carolina (USC) has been collaborating with the South Carolina Army National Guard (SCARNG), Army, and DoD to help fully develop the needed capabilities pertaining to CBM and now PM. This effort has resulted in the Center for Predictive (CPM) within the USC Department of Mechanical Engineering. CPM hosts several aircraft component test stands in support of PM objectives. Since its inception, the center has strived to take on new tasks and responsibilities in order to satisfy the needs of defense aviation. Activities at the center include, but are not limited to: researching and testing aircraft components for the U.S. Army in order to increase time between overhauls, increasing mission availability and readiness, creating new diagnosis and prognosis algorithms in order to improve the operations of various aircraft (Apache (AH-64), Osprey (V-22), Black Hawk (UH-60) and Chinook (CH-47)), and improving and/or creating new sensors to advance the onboard HUMS. These new enhancements also reduce improper and unnecessary maintenance tasks which can account for 33% of total maintenance costs. The US industry spends over $260 billion each year on maintenance, and, because of improper maintenance, 85 billion of these dollars are lost annually (Mobely, 2002). Other benefits include improved safety, reduced casualties, and increased morale. To enable this practice, a high priority should be placed upon current sensor data as well as historical data including those coming from digital source collectors (DSC) and maintenance records (Goodman et al., 2009, Edwards et al., 2013).

3 Predictive Maintenance Methodology

The PM methodology starts with various data sources, including historical, current, and testing data, to create the parameter that needs to be monitored on a particular component. These data sources can then be formatted using tools such as NLP and data fusion to create and be used in a predictive model. This model can determine expected outcomes like RUL, failure points, and how to improve asset management. The transformed data can then be sent to individual users and decisions about how to maintain the component can be made automatically. This process reduces maintenance burden on leadership, operators, maintainers, and engineers. All of this information will also be available in dashboards to inform all users on current trends with the fleet.

3.1 Data Collection, Processing, and Analysis

For a component or a process to be connected to IoT it needs to collect data via a sensor. So it is a natural fit between PM and IoT since the foundation which it bases all of its reasoning off of is a sensor. Selecting the proper sensor(s) to monitor a particular component is critical to being able to collect the highest quality data. Just as important as the sensor is the rate at which data is acquired. The collection frequency needs to be a balance between having too much data that it is no longer useful and collecting such a small amount that those important characteristics cannot be interpreted. Different sensors can monitor aspects of a component’s health, but data from multiple sensors can also be integrated together to create new condition indicators (CIs) that can give an entirely new perspective on the piece of equipment. By utilizing tools like advanced signal processing and data fusion an aircraft can become more reliable. The usefulness of the on-board sensors is optimized without the cost or weight of new components. It is also important to audit sensor readings periodically so that it can be confirmed that the proper parameters are still being collected, and have not changed over time.

Historical data is valuable when trying to establish and adjust procedures that occur when a component needs to be repaired. It allows an engineer to alter CIs thresholds that were once purely based on theoretical work and can now be backed up with reliable data from the field. This makes the predictions upon which they are based more accurate and ensure that the component being removed is actually faulted.

Historical data does not only include health usage monitoring system (HUMS) data. It can also utilize standards, regulations, manuals, and historical logs to capture the human factor of maintenance. This creates a reliable prediction that is based on maintainers' past experiences. Capturing this knowledge and effectively relaying it to a maintainer, gives someone who may have relatively little experience the same amount of wisdom that a seasoned veteran would have. Reviewing this data can also help determine common failure modes and establish methods for how they can be fixed or deterred. Periodic review will also help confirm that the appropriate type and amount of data is being collected to accurately identify faults.

3.2 Statistical Analysis and Modeling

Proper implementation of a new prognostics system is critical for ensuring that maintenance procedures are carried out at the correct intervals. Improper maintenance intervals could lead to failure of a component even shortly after an aircraft has been serviced. To assure this step is completed fully, the decision needs to be based on solid models as well the current sensor readings coming from the aircraft. Once these rules and standards are established for determining when a component is faulted, a statistical algorithm is used to assess when a safe removal time will occur. To complete this there are a few criteria that need to be established to better understand the type of prognostic tool to be used: 1.) Has the type of fault been determined? 2.) How long has the fault been active for? 3.) What is the severity of the fault? Justification for which statistical algorithm that is used is dependent upon these criteria. The goal of determining RUL is to output a reliable time interval and to minimize the number of false alarms which is a key part of decision making for leadership.

3.3 Asset Management and Dashboard Creation

After the analysis has been completed, the results must be presented to the users. Each user will have different needs and can include personnel in leadership, engineers, maintainers, and operators. In order to address the needs of different users, the information displayed can be tailored to fit these requirements. The data can also be displayed in different forms including dashboards and reports. After a user is presented with the results from the analysis, they will need to use this information to perform an action as suggested by leadership. These actions can include maintenance recommendations, report creation, and work-order generation. These actions need to be backed up with reliable data and analysis so leadership can feel confident with their decisions. This makes sure that no unnecessary repairs are conducted and the maintainer knows exactly what needs to be repaired and how to complete the action. Historical data, combined with the data currently coming from the component in the demonstration, can be easily displayed so that those in a leadership role can make timely decisions about a faulted component.

4 Leveraging IoT to Improve Aviation Maintenance

4.1 Native Environment

The major advantage of conducting PM in an IoT environment is that all of the processing, storage, and calculations are conducted in a single place. This creates an edge when trying to complete a task in an industry that has as many regulations as aviation does. With all processes connected it adds accountability to each user. They have to get input from everyone involved so that an individual cannot skip steps to make an action go faster or try and hide the work being done. By leveraging IoT, the maintenance process can run more efficiently and faster. Leadership is now aware of all decisions being made due to the connectivity of all the processes to one centralized place. The decisions will be more knowledgeable and can yield better results.

The single environment of IoT also allows for better management of parts tracking and the historical data of these parts. It is always a concern about how secure a database is when dealing with a defense entity, especially in an IoT environment. Security of the data needs to be a high priority to make sure that everything is being done to keep the integrity of the data while not detracting from the efficiency of the process. Data being collected from the HUMS unit on the aircraft should be downloaded and added to server as securely as possible. Since the inventory of components, sensor data, and historical maintenance records are now hosted together more information can be gathered about a particular component that is going to be used on an aircraft. Personnel can know exactly when a component was overhauled, and how long it has been in storage, which aircraft it has flown on and for how long. CIs associated with the component can also be captured, making it easier to isolate faults in an individual component rather than the entire aircraft. Diagnosis capabilities become stronger as a result of having complete information for an article. By tracking parts and associating individual records with one component, changes in the maintenance of that article, whether it is a design change, tooling change, or procedural change, can now happen faster.

4.2 Automation

Since all of the processes are connected it requires less human interaction for a maintenance work order to be processed. By having prognostic algorithms, the system can determine the best time to complete a maintenance action. RUL should be considered with the routine maintenance schedule in mind so that if the component is predicted to fail in 530 hours, and there is scheduled maintenance occurring in 500 hours, then the component should not be removed until the scheduled interval. This reduces the burden on the maintainer and assures it does not become a risk to the operator on a future mission.

Automated work-orders reduce the burden on leadership and increase maintenance productivity. Due to the automation of this process because of IoT environment, it now benefits other departments such as supply chain. It is known when a part is going to be removed so a smaller inventory of parts can be kept on hand and the component can be shipped only when necessary. When the maintainer is scheduled to do the repair the component is already at the facility, and does not spend time somewhere it is not needed.

Having a process that is self-sustaining also allows for it to become “smarter” as more data is added to the database. By using cognitive features like machine learning to improve condition indicators without additional user input, the thresholds can change overtime, as well as the maintenance recommendations. This also makes it easier to find an imperfection in the process.

5. Optimized Scheduled Maintenance

5.1 MSG-3 Methodology

The ultimate goal in creating an optimized scheduled maintenance plan through MSG-3 is to be able to adequately use all of your resources to create the best result. This includes being able to produce a good product while making use of resources, including cost and time, and not affecting the morale and safety of the personnel that are involved in the maintenance process. The maintenance steering group (MSG) process was originally created to form a standardized decision making process that could be used for scheduled maintenance on fixed wing aircraft. Over the years different iterations have been established, slowly including PM attributes as they became more valuable throughout the industry. The advantage of a task oriented program is that it is based on specific functional failures and the reliability of each piece of equipment being monitored. Tasks are selected depending on the amount of cost, difficulty, and the safety effects on the crew. A general list of tasks includes lubrication, visual check, inspection, restoration, and discarding the component. These functions are found in each of the maintenance program groupings: zonal, systems and power plant, structures, and lighting and high intensity radiated field (Ackert, 2010).

Working groups (WG) are created from the four areas (Zonal, Structural, Systems, and L/HIRF) to develop minimum scheduled tasking intervals consisting of operators, maintainer, engineers from industry, and other relevant positions. These working groups are overseen by multiple entities to ensure that their recommendations are sufficient to be included in the maintenance plan. The maintenance steering committee (MSC) is made up of various representatives to define the systems to be analyzed, direct activities of the WG, and to remain in contact with all of the necessary partners. The OEM and a contracting organization will work together to achieve a balanced recommendation and provide data, models, reliability metrics, and any other significant items to the WG.

Before WG activities can start there are critical pieces that need to be setup so that their job can be done efficiently and yield the best results. A contractor will prepare and provide each WG with necessary documentation including technical description of the aircraft configurations, data, results, models/algorithms, presentation overview slides, and other training materials. They will also prepare and provide data, results, models, and technical manuals that are needed. All of these files need to have a central location in the form of a secure interactive web-based environment so that file exchange and user interaction can occur easily.

5.2 Combining Optimized Scheduled Maintenance with HUMS data

Although there are many benefits to an optimized scheduled maintenance plan, it still does not take full advantage of the on-board HUMS system and IoT. This is because most tasks are based on time metrics like calendar time or flight hours, and not based on the actual degradation of the component that is being monitored. This way of scheduling tasks is also disadvantageous when accounting for the wide variety of operating conditions of the aircraft. Since mission profiles can change drastically from one aircraft to another, the failure time can also vary greatly. Due to this variation the worst case scenario has to be accounted for causing more part replacements to occur well before they are needed.

By using PM on an individual aircraft through the HUMS system and monitoring the historical data a better prediction can be made about component replacement. The chances of a component failing greatly increase after maintenance is performed due to human error during the installation. Using HUMS also gives another opinion to the health of the aircraft because it can detect degradation that might not be seen during a visual inspection. It is also a more exact way of measuring a fault because trends in the data give you a quantifiable number to measure against versus a visual inspection which might determine that the fault has not grown by a considerable amount. Being able to leverage PM through HUMS data and connecting it with the proper scheduled interval with MSG-3 allows for more inputs that can be taken into IoT. Having all of this impactful data in one location, connected to all necessary personnel, allowing real-time decision making about an aircraft’s maintenance needs, is an asset to all users involved.

5.3 Benefits and Training

The benefits an optimized scheduled maintenance combined with PM can include a reduction of maintenance burden, high reliability, increased safety, increased cost avoidance, and improved morale. These benefits will increase as the process continues and users become more familiar with how to use it. CPM at the University of South Carolina has experience at creating these demonstrations and has recently created one using the AH-64 intermediate gearbox. This demonstration shows a user how a fault on a gearbox can be detected by a sensor, analyzed using PM techniques and then displayed and processed into a work order quickly using IoT. This demonstration adds to the list of components that are able to be tested at the facility.

6 Center for Predictive Maintenance Capabilities and Outcomes

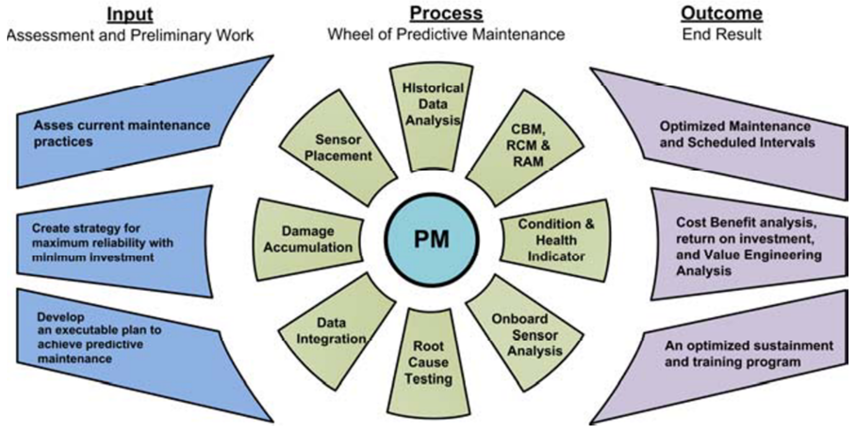

Fig. 1. Three steps are used to create an effective PM program

CPM at the University of South Carolina has been working on improving this process over the years. Flight data and testing data are important for improving and disproving the validity of CIs (Allen, 2015). Once optimal thresholds are determined for these values it will ultimately reduce the amount of false positives and increase the amount of true positives (Cao, 2013). CPM has been focused on component testing to improve condition indicators and independent projects to better the entire PM program. As seen in Figure 1, there are three major steps to implementing a successful program in industry. The first step is assessing current procedures, creating a strategy to maximize reliability while using minimum investment, and developing and easily executable plan. The next step is analyzing the different needs in the program, which has been the focus of CPM's different research projects. The final step is the outcome, which should be an optimized scheduled maintenance plan that is based on sound engineering and will have a high return on investment.

6.1 CPM Testing Facility

CPM currently operates several test stands that have helped support PM objectives for aviation. The main objective for testing is to improve aircraft reliability through the testing of naturally-occurring and seeded-fault testing. Other benefits from testing also include development of new sensors and improved CI algorithms that can be created using data. These test stands include an auxiliary power unit (APU), a main rotor swashplate (MRSP), and a tail rotor drive train (TRDT). Each test stand emulates the normal flight conditions experienced by the components. Structure, instrumentation, data acquisition systems, and supporting hardware are installed according to military standards. The test stands are designed and built to accommodate the use of various HUMS. USC's own data acquisition results have been validated with data obtained from actual airframes. The testing facility is capable of being modified to test new and existing drivetrain components of military and civilian aircraft, including the ARH-70, CH-47, and UH-60 drivetrains (Bayoumi et al., 2008, Goodman et al., 2009, Edwards et al., 2013).

6.2 Project Results

Multiple faults have been examined using the TRDT test stand. One fault was of the tail rotor gearbox leaking grease through its input and output seals. An experiment was designed to create a worst-case scenario for a leaking output seal on three different high-life gearboxes, which were to be run for 500 hours in a seeded fault condition. Although previously considered impossible, during the study it became evident that grease freely moves from the main gear compartment into the static mast. The three gearboxes tested survived 490, 487, and 573 hours after fault seeding, and numerous vibration and thermal observations were recorded as the gearboxes approached failure. Benefits seen from this project were a return on investment of 20.2:1, increased readiness, and fewer maintenance actions needed (Goodman et al., 2009).

Another set of components studied were the hanger bearings on the AH-64. The objective of the seeded fault test was to examine whether existing CIs would respond to failure modes simulated by seeded faults (Prinzinger et al., 2012). The faults were tested for over 8000 hours with no substantial evidence that the CI values were responding as expected. As a result CBM credit was sought and approved for extending the time between overhaul (TBO) for the hanger bearing from 2750 to 3250 hours leading to a new airworthiness release for hanger bearings (Cao, 2013)

An Advanced Vibration Sensing Radar (ADVISER) for condition monitoring experiment tested Honeywell's ADVISER sensor and its potential diagnostic and prognostic capabilities. The sensor measures the phase change between input and output signals caused by the target displacement. The ADVISER sensor has a wide field-of-view giving it the capability to monitor more than one component at a time. As a result from this testing, a new, platform independent, non-contact sensor was validated for CBM use. This could lead to a reduction in the required number of sensors and consequently overall weight (Bharadwaj et al., 2013)

Another effort was to apply NLP techniques to improve reliability and reduce costs of V-22 aircraft. The program had three main objectives. First, research and develop methods to align maintenance actions, based on what was reported in the free text fields with entries in the aircraft's technical manual. Second, trim the unwieldy technical manual of redundant entries, for which entries that are semantically similar but syntactically different needed to be recognized. Third, research the suitability of current ontology technologies for creation of a maintenance "reasoner" knowledge base. Value-added results included: creation of a new text pre-processor specific to maintenance records, that improves the performance of baseline NLP part-of-speech tagging and entity extraction methods, and a program to identify similar text entries amongst large textual data stores and categorize them by degree of differentiation (Bokinsky et al., 2013).

7 Conclusion

There are many advantages that can be gained, in comparison to standard maintenance practices, by having a proper understanding of the PM process and applying it in an IoT environment. The failure points of the aircraft should first be established by creating an optimized maintenance plan through input of the industry community and regulatory bodies. This scheduled maintenance should be based on safety, reliability, and the cost repairing the aircraft. It can be further enhanced by HUMS capability on the aircraft. PM through the use of historical records, testing, and technical documents allow the user to advance their knowledge of the health of components further than basic inspections could yield. When PM is based in an IoT environment it creates a streamline process that leads to less downtime and more informed decisions on the maintenance that needs to be performed on the aircraft. Proper implementation will help reduce maintenance burden, prevent unnecessary maintenance actions, increase safety, increase system readiness, refine the maintenance process, and ultimately improve component design.

CPM has been heavily involved in this effort in many projects to make sure that PM is advancing to its full capability in the field. The philosophy has worked well for the center and lead to an increase in cost avoidance for the Army on rotor blades, tail rotor gearboxes, and hanger bearings. This also resulted in: an increased time on wing for tail rotor gearboxes and hanger bearings and increased health monitoring capability through tachometer clearance, enhanced natural language processing techniques, sensor development, and increased diagnostic algorithms. This solution has already shown results and will continue to do so, not just on aircraft, but to any system to which it is applied.

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The Effects of Nanoparticle-Enhanced Oil on the Efficiencies of Internal Combustion Engines

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Abstract. This study was conducted to investigate the effects of nanoparticle-enhanced oil on the state variables of internal combustion engines not limited to gas turbine engines. Two samples of nano-oil were tested: one sample contained AeroShell 560 with diamond nanoparticles additives while the other constituted of zinc sulfide, boron nitride, and graphene nanoparticles. Thelubricating oils were tested in a UH-60 Blackhawk Auxiliary Power Unit (APU) to examine the influence of such oils on the operating temperature and efficiency of the engine. Experimental results from the nano-oil study suggest that the use of nanoparticle-enhanced oils could provide significant improvements in engine efficiency by reducing vibration and temperature of the engine. To further characterize the effects of nano-oils, a supplementary oil study was conducted on a small 4-stroke engine. The same oil samples were tested in the experiment with the addition of a conventional Pennzoil High Mileage 5W-30 and a diamond nanoparticle-enhanced Pennzoil High Mileage 5W-30. This supplementary investigation confirmed that nano-oils improve fuel efficiency of combustion engines by reducing engine temperature and vibration. However, some oil samples yielded anomalous results, discussed in later sections of this article.

Keywords: *Auxilliary Power Unit, Nano Oil ,Fuel Efficiency, Small Engine*

1 Introduction

1.1 Background and Previous Research

Oil is used in turbine engines to lubricate bearings, gears, and other rotating components. Energy can be lost through heat, vibration, and wear generation, which are caused by friction between moving parts. This study examines the effects of oils containing graphene, zinc sulfide, boron nitride, and diamond nanoparticles in internal combustion engines.

Previous studies have shown that nano-oil additives have the ability to significantly reduce friction and wear in gear boxes and engines. It has also been shown that nanodiamond particles can provide large efficiency improvements in

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engines [1, 2, 3]. These studies show the promising benefits associated with the use of nano-oils.

1.2 Problem Definition and Methodology

This research aims to further enhance the understanding of nano-oil properties and determine any benefits associated with the use of nanoparticle oils in internal combustion engines. Based on the previous studies, nano-oils have the ability to reduce friction, which would, in turn,reduce wear while improving fuel efficiency. This may result in large cost savings if the proposed oil proves effective and is implemented across entire fleets. Maintenance costs may also be reduced if the degradation rate of wear is reduced.

Due to the limited availability of research funds, a preliminary oil study was performed on the intermediate gearbox (IGB) of an Experimental Drive Train to select at least two oil samples that showed potential for improvements in engine efficiency. Five oil samples were tested during this experimental phase: a conventional AeroShell 560 oil sample, a diamond nanoparticle oil sample, and three oil samples containing zinc sulfide, boron nitride, and graphene nanoparticles.Subsequently, the best two nano-oil samples were tested in a UH-60 APU (turbine engine) and a 5.5 HP internal combustion engine, referred to as the small engine. The collected data was analyzed against experimental data from tests using baseline oils (AeroShell 560 and Pennzoil High Mileage 5W-30) to identify the effects of nano-oils on combustion engines. The exact composition of nanoparticles in each oil is proprietary information and was not disclosed as part of this study; however, characterization of oil samples was performed using optical microscopy, transmission electron microscopy, and viscosity analysis. For easy reference, diamond nanoparticles-enhanced oil will be referred to as ‘Batch A’, while nano-oils containing zinc sulfide, boron nitride, and graphene nanoparticles will be referred to as ‘Batch B’. The appended integers to the oil samples indicate differences in the concentration of nanoparticles within the sample. Figure 1 highlights the experimental phases of this study as well as the oil samples and state variables examined during each phase.

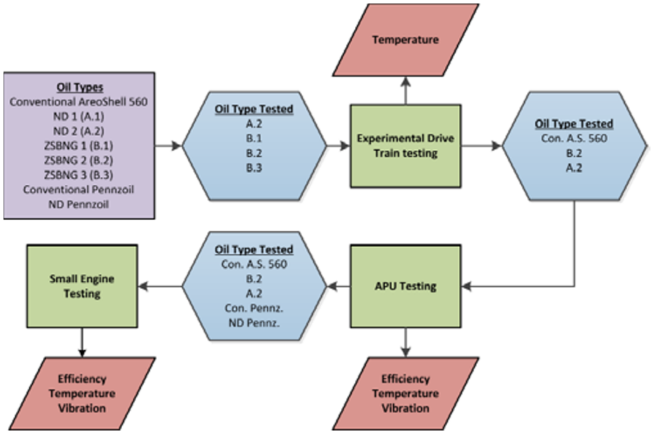

Figure 1. Experimental Flowchart

2 Test Stand Descriptions and Procedures

2.1 Description and Procedure fo rExperimental Drive Train

The Experimental Drive Train (EDT)is composed of several AH-64 drive train components, driven by a 5.5 HP motor.The test stand is used to develop new technologies while using less resources than the main test stand. The IGB, located at the tail end of the shaft,wasequipped with four thermocouples at the Input Roller Bearing (IRB), Input Duplex Bearing (IDB), Output Roller Bearing (ORB), and the Output Duplex Bearing (ODB).

Four runs using conventional AeroShell oil were performed first, followed by four runs with each nano oil. The oils tested include: Conventional, Batch A.2, Batch B.1, Batch B.2, and Batch B.3. All oils were tested four times, and each run lasted for 50 minutes with the drive shaft operating at a speed of 4,863 rpm. The only source of data collected for this test was temperature measured at each of the bearings. The IGB was flushed multiple times with conventional oil between each run to remove any remaining nanoparticles.

2.2 Description and Procedure fort he Auxiliary Power Unit

During start-up, the fuel boost pump injects fuel from the on-board fuel tank, through a filter, and then to the fuel inlet manifold on the APU. After the turbine reaches full speed, it draws fuel on its own and the boost pump can be turned off. This fuel continuously combusts and causes the turbine to rotate, which transfers torque through the reduction drive assembly to the output shaft. The water brake dynamometer is attached to this shaft and is controlled by water pressure from a hose. This is connected to a pressure regulator then to a manual valve outfitted with a pressure gauge. The pressure regulator prevents inconsistent water pressure from affecting the torque applied by the water brake. The flow rate of water is adjusted to create a consistent torque load applied to the output shaft of the APU.

The APU runs were performed uninterrupted for 45 minutes. Vibration, oil temperature, exhaust temperature, RPM, fuel consumption, and torque readings were collected throughout the duration of each run. In addition,local climate conditions, including humidity, ambient temperature, and barometric pressure, were recorded throughout each run. Seven runs were performed for Conventional AeroShell, Batch A, and Batch B oils. The APU was flushed with conventional oil between Batch A and Batch B runs to remove any leftover nanodiamond particles. The measurements taken during the last 30 minutes of each test were compared.

Data was analyzed using RStudio and Microsoft Excel. The overall efficiency, oil temperature, and vibration data were compared between oil samples. The fuel flow rate was not directly compared, because slight inconsistencies in RPM and torque were present due to small variances in water pressure and human error associated with manually adjusting the torque. To account for this, the overall efficiency of the APU was examined in this studyusing Equation 1, which relates the output power (W) to the input power from the fuel (E_{in}). The output power was calculated using Equation 2. The energy density of the fuel was calculated by using Equation 3.

$$APU\ Efficiency = \frac{W}{E_{in}} \quad (1)$$

$$Output\ Power\ (W) = \frac{RPM\ \times Torque}{5252} \quad (2)$$

$$E_{in} = Energy\ density_{fuel} \times m_{fuel} \quad (3)$$

Engine efficiency accounts for all system losses, highlighting its validity as a comparative indicator for the oil samples, it also provides a way to normalize fuel flow data so that fuel consumption can be compared. Since efficiency represents the ratio of output power to input power, it can be used to study fuel flow for each oil type at specific horsepower values.

Vibration was measured with an accelerometer and the data was collected at 20 kHz. This resulted in about 15,000,000 data points per run which were analyzed by performing a Fast Fourier Transform (FFT) and by calculating the Root Mean Square (RMS) value of each set of data. A FFT transforms the vibration data from a time domain to a frequency domain, outputting vibration magnitudes with respect to the frequency at which they occur. This approach is useful because different rotating components vibrate at different resonance frequencies. The RMS value allows for comparisons of the overall vibration energy between oil types, while the FFT enablesthe evaluation of vibration data occurring at individual frequencies.

Multiple studies suggest that variations in ambient temperature and pressure can affect turbine efficiency [4, 5], therefore,a correction factor was applied to the fuel flow. The variable $W_{corrected\ fuel,}$ shown in Equation 4, is the fuel flow after the correction is applied.The variable W_{fuel} represents the measured volumetric fuel flow.

The variable δ is the ratio of measured barometric pressure to a standard sea level barometric pressure, and θ is the ratio of measured ambient temperature to a standard temperature of 15°C. The corrected volumetric fuel flow is multiplied by the density of the fuel to determine the mass flow rate of the fuel [6].

$$Corrected\ Fuel\ Flow\ (W_{corrected}) = \frac{W_{fuel}}{\delta\sqrt{\theta}}$$

Oil temperature was also corrected for effects caused by the difference in ambienttemperature as shown in Equation 5[7]. After the average oil temperature throughout each run was determined, a Tukey Honest Significant difference (HSD) test was performed to compare the runs for each oil type.

$$Correction\ for\ Oil\ Temperature\ (T_{oil-corrected}) = T_{oil} + (100°\text{F} - T_{ambient})$$

2.3 Description and Procedure for the SmallEngine

The Small Engine Test Standcontainsa 5.5 HP 4-stroke engine with a fuel flow meter. RPM, torque, and ambient conditions were measured by the dynamometer. A DAQ utilizing LabVIEW software was used for gathering oil temperature and fuel flow data.

The engine was run initially for ten hours with conventional motor oil to allow for break-in. After this, four runs were performed for each type of oil. Five types of oil were tested: Pennzoil High Mileage 5W-30, Pennzoil High Mileage 5W-30 with a nanodiamond additive, AeroShell 560, AeroShell 560 with nanodiamond particles (Batch A.2), and AeroShell 560 with graphene, zinc sulfide, and boron nitride particles (Batch B.1). The nanodiamond additive used in the Pennzoil oil is a blend formulated by NanoPro specifically for pistons engines. The Pennzoil and AeroShell base oils were used to flush the engine between runs,removingnanoparticles that were left in the engine and returningthe engine to a baseline state. ANOVA and Tukey's HSD were used for analyzing data from the last 30 minutes of each run during which the engine was assumed to be at steady state. Ambient condition correction factors were applied to the small engine as well, however the coercion factor equations used are specifically for piston engines. Equation 6 shows the correction factor used to account for variances in ambient barometric pressure and temperature. The variable *P* is ambient barometric pressure in millibars, and the variable *T* is ambient temperature in degrees Celsius.

$$cf = 1.176\left[\left(\frac{990}{P}\right)\left(\frac{T+273}{298}\right)^{\frac{1}{2}}\right] - 0.176 \qquad ($$

2.4 Procedure for Offline Analyses-Viscosity and Microscopy

Viscosity was measured using a Brookfield Engineering Co. LVDV II viscometer, a cone and plate type rotary viscometer. The dynamic viscosity of oil samples (in mPa·s) were obtained from shear stress in the fluid from pre-calculated values in the software. The viscometer is accurate to within ±1.0% and reproducible within ± 0.2% [8]. Conventional AeroShell, Batch A.2, and Batch B.1 samples were tested at each ten degree increment ranging from 20°C to 90°C. Nine measurements were taken at each temperature and averaged together.

Two different microscopes were used to observe the oils and their subsequent particle clumping. During the mixing process of the oils, clumps of particles were visibly noticeable in the original Batch B oil. To determine the size of these clumps, a KEYENCE VHX-5000 optical microscope with a lens capable of 5000x magnification was used to examine and measure the particle clumps in Batch A.2 and Batch B.1. A Hitachi H8000 Transmission Electron Microscope (TEM) was used to measure the size of individual particles in the Batch B.1 oil. This device has a resolution of 1.5 nm and a magnification of 2,000-800,000x.

3 Results and Discussion

3.1 EDT Results

Temperature data from the last 20 minutes of each run was analyzed in RStudio. The last 20 minutes of data were chosen to give the gear box adequate time to warm up. ANOVA and Tukey's HSD tests were used to analyze the data. Table 1 shows the results from EDT testing. The difference in average temperature between the conventional oil and each nano-oil, at each location, is shown in this table. A positive value indicates that the temperature rose by that amount, while a negative value indicates that the temperature decreased by that amount.

Table 1: EDT Temperature Differences Between Conventional AeroShell and Nano Oils (°F)

Oil Type	IDB	IRB	ORB	ODB
Batch A.2	-2.45	-0.95	-1.08	-1.19
Batch B.1	-8.06	-10.20	-9.39	-13.46
Batch B.2	-2.78	-8.65	-10.93	-11.83
Batch B.3	5.45	-7.84	-15.53	-13.07

From this table, it is evident that all of the nano-oils reduced the temperature in the gearbox for at least three of the four thermocouples. The disparity in the temperature reduction values associated with Batch A.2 and Batch B.2oil samples can be attributed to the higher concentration of nanoparticles in Batch B. While graphene has an extremely high thermal conductivity, diamond nanoparticles have a higher thermal conductivity than any of the particles found in Batch B. To provide greater temperature reduction benefits, Batch B must have a higher concentration of particles, or provided much better friction reduction. The exact concentrations are proprietary and are only known by the manufacturer. The presence of nanoparticles in nano-oils explains theimprovements in heat transfer performance because the nanoparticles, especially diamond and graphene, enhanced the thermal conductivity of the base oil.Batch B.1 had the lowest nanoparticle concentration out of the Batch B oils, and the findings suggests that it caused the most uniform heat transfer, likely due to its lower viscosity which allowed for easy flow throughout the gearbox.As a result of this testing, Batch B.1 was selected for testing in the APU, along with Batch A.2. For the rest of this document Batch B.1 will be referred to simply as Batch B and Batch A.2 will be referred to as Batch A.

3.2 APU Results

Each run was tested for consistency before being analyzed with an ANOVA test and a Tukey (HSD) test in RStudio. A t-test was performed to determine the percent error in the data for a 95% confidence interval.Equation 1was used to find efficiency from horsepower and flow rate. The data analyzed from the final 30 minutes of each run consisted of approximately 1,800 data points for fuel flow and efficiency. Torque and RPM were sampled more frequently and consisted of about 18,000 data points. The large number of data points caused the percent error to be extremely small.

Efficiency was calculated for Conventional oil and then Batch A and Batch B oils. Batch A and Batch B oils were compared to Conventional AeroShell oil. The results suggested that bothnano-oils improved overall APU efficiency. The p-value was calculated as part of the Tukey HSD test to determine if the values were significantly different with final values ranging from zero to one. The p-value was less than $2x10^{-16}$ for all of these calculations, providing very strong evidence that the means were not statistically different. This test was performed for a 95% confidence interval. The average values for fuel flow, torque, RPM, and efficiency are shown in Table 2.

Table 2: Efficiency and Fuel Flow Results

Oil Type	Average Corrected Fuel Flow (mL/s)	Average Output Torque (ft-lb)	Average RPM	Average Efficiency (%)
Conventional	12.93	14.80	12009.62	5.54
Batch A	12.75	14.77	12000.03	5.59
Batch B	12.50	14.76	11990.02	5.70

Oil temperature was analyzed from the 15 to 45 minute portion of each run. An ANOVA test and a Tukey (HSD) test were performed using RStudio. The correction factor was applied by using Equation 6 which corrects the oil temperature to represent the results that would be expected for an ambient temperature of 100°F (37.78°C). As was the case for conventional oil, the correction for ambient temperature effects significantly reducedthe percent error in the data. The average Batch B oil temperature was noticeably higher than that of Conventional and Batch Aoils.

Batch A oil appeared to lower the oil temperature by 1.4 degrees Celsius. However the p-value for this comparison was 0.1755, indicating that the means are not statistically different, therefore, there was no statistically significant difference in temperature. Batch B increased the temperature by 6.93 °C. The p-value for this comparison was $1x10^{-7}$ indicating that there was a definite statistical difference between the mean oiltemperature of the conventional oil and Batch B oil.It is evident that the Batch B oil operated at a much higher temperature than the other two oils. An increase in temperature could have been a result of increased friction or from increased heat transfer from a heat source, such as the combustor.

Table 3: Oil Temperature Results

Oil Type	Oil Temperature (°C)	Corrected Oil Temperature (°C)
Conventional	81.90 ± 4.44	99.78 ± 0.73
Batch A.2	82.77 ± 2.68	98.38 ± 1.46
Batch B.1	98.32 ± 3.78	106.71 ± 1.80

Vibration data from all seven runs were averaged so that it could be compared to the other oil types. An ANOVA test and a Tukey (HSD) test were performed using RStudio. The average peak magnitude for Conventional oil was 2.53 ± 0.66 g, and the average RMS was 25.90 ± 5.46 g and occurred at a frequency of 6,418.41 Hz.The average peak magnitude for Batch A was 1.65 ± 0.67 g, and the average RMS was 20.22 ± 4.07 g, and occurred at a frequency of 6,413.69 Hz. The average peak magnitude for Batch B was 1.40 ± 0.48 g, the average RMS was 19.07 ± 3.06 g, and occurred at a frequency of 6,406.71 Hz.The values in Table 4 represent the reduction in vibration when using each nano-oil instead of Conventional oil.

Table 4: Batch A and Batch B versus Conventional Results

Vibration Data for Nano-Oils Compared to Conventional Oil				
Oil Comparison	**Peak Magnitude (g)**	**p-value for Magnitude**	**RMS (g)**	**p-value for RMS**
Batch A vs Conventional	-0.88	0.04	-5.68	0.06
Batch B vs Conventional	-1.12	0.01	-6.82	0.02

3.2.1. Discussion of APU Results

The experimental findings show that there was an increase in efficiency for Batch A and Batch B oils. Batch A reduced the peak vibration by 35% and the RMS by 22% while Batch B resulted in a 44% reduction in peak vibration and a 26% reduction in the RMS, suggesting that friction was reduced by a substantial amount. Vibration can result from contact of surface asperities during mixed-boundary lubrication and can greatly be reduced when an elastohydrodynamic regime occurs. This type of lubrication involves a compressible layer of oil that provides complete separation of the two surfaces. Oil with a higher viscosity usually results in a thicker boundary layer between surfaces. While this reduces friction between components, drag forces in the oil increase. The results suggest that both nano-oils improve the fluid film, resulting in decreased vibration and increased efficiency.

The increase in temperature for Batch Boil is an unexpected outcome and requires additional testing to completely determine the cause. Increased friction usually causes increased vibration and heat. Batch B most likely reduced overall friction because of the heat reduction in the IGB, the efficiency improvement in the APU, and the vibration reduction in the APU, suggesting that the higher APU oil temperature resulted from other factors. The average temperatures during the 15 to 45 minute portion of the runs are shown in Figure 2. A higher combustor temperature, as seen with Batch B,signifies increased efficiency. Less heat may be generated by friction, but more could be transferred from the rest of the engine. This suggests that Batch B conducted heat much more efficiently than the other oils.

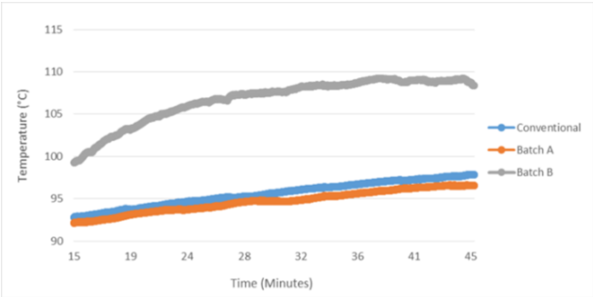

Figure 2: Transient APU Oil Temperature

The runs were not performed long enough for steady state temperatures to be reached because the APU on an UH-60 usually runs for less than 30 minutes before take-off, in which it does not reach steady state, therefore, analyzing steady-state data would not provide useful information for realistic scenarios. Figure 2 suggests that Batch B may have decreased friction, but may have also had a lower specific heat which caused its temperature to rise at a faster rate. The combustor may have also been operating at a higher temperature because of reduced friction. Hence, the oil temperature increase was most likely caused by an increase in the combustor temperature.Oil filter clogging could have also been a likely cause of increased temperature for Batch B oil. The clogging of the filter reduced oil flow, resulting in higher oil temperatures due to slower heat exchange. Both nano-oils provided overall efficiency improvements. While the reduction in fuel consumption is fairly small, cost-savings could be significant in the long-term.

3.3 Sm all Engine Res ults

The efficiency results for each run for all five types of oil along with the average efficiency for each type were calculated. The average efficiency values for Pennzoil, Pennzoil with diamond nanoparticles, Conventional (AeroShell 560), Batch A.2, and Batch B.1 were 21.29%, 20.88%, 21.83%, 21.58%, and 22.43% respectively. The efficiency was higher for conventional turbine oil than for Pennzoil oil. The use of nanodiamond (ND) particles reduced the efficiency in both Pennzoil and AeroShell

560 while the use of Batch B.1 resulted in increased efficiency. The results, when calculated with a Tukey HSD test, are shown in Table 5.

Table 5: Comparison of Small Engine Efficiency Results

Oil Type	**p-value**	**Difference (95% confidence)**
Pennzoil		
Pennzoil w/ND Additive	$< 2 \times 10^{-16}$	-0.44%
Conventional (AeroShell 560)		
Batch A.2	$< 2 \times 10^{-16}$	-0.26%
Batch B.1	$< 2 \times 10^{-16}$	0.06%

The average corrected temperature values for Pennzoil, Pennzoil w/ND additive, Conventional (AeroShell 560), Batch A.2, and Batch B. 1 were calculated to be 106.81°C, 104.73°C, 105.28°C, 103.52°C, 103.64°C respectively. The results, when calculated with a Tukey HSD test, are shown in Table 6.

Table 6: Comparison of Small Engine Temperature Results

Oil Type	**p-value**	**Difference(°C) (95% confidence)**
Pennzoil		
Pennzoil w/ND Additive	$< 2 \times 10^{-16}$	-1.67
Conventional (AeroShell 560)		
Batch A.2	$< 2 \times 10^{-16}$	-1.88
Batch B.1	$< 2 \times 10^{-16}$	-1.63

The average RMS values for Pennzoil, Pennzoil w/ND additive, Conventional (AeroShell 560), Batch A.2, and Batch B.1 were 1.879g, 1.886g, 1.957g, 1.971g, 1.656g respectively. The Batch B.1 runs had the lowest RMS values and using this oil instead of conventional oil resulted in a 15.4% reduction in RMS. The results, when calculated with a Tukey HSD test, are shown in Table 7.

Table 7: Comparison of Small Engine Vibration Results

Oil Type	**p-value**	**Difference(*g*) (95% confidence)**
Pennzoil		
Pennzoil w/ND Additive	0.793	0.007
Conventional (AeroShell 560)		
Batch A.2	0.846	0.015
Batch B.1	1×10^{-7}	-0.300

3.4 Offline Analysis Results-Viscosity and Microscopy

The samples were measured at various shear stresses and were determined to be Newtonian fluids, meaning the shear stress varied linearly with shear rate. Batch A was found to have a higher viscosity than Conventional oil, and Batch B has the highest viscosity at every temperature. The oil temperature in the APU was between 85°C and 105°C for most of the runs. At 90°C, the viscosity of Batch B was 17.97% higher than the viscosity of the Conventional oil, potentiallyreducing surface to surface contact, but also increasing drag forces associated with spinning oil bearings.

The optical microscope showed that there were large particles present in the initial Batch B oil, some of these particles were over 200μm. Due to the large size of the nanoparticles, NanoPro MT developed a second Batch B oilby filtering the initial Batch B oil. While the particle size was reduced, they were still measured to be in the 20 to 40μm range. The APU has a 10μm oil filter, so these particles could still clog the filter.The nanodiamond particle clumps in Batch A are much smaller than the ones present in Batch B, when viewed through an optical microscope, the majority of the clumped particles were measured to be in the 6 to 12μm range.The Batch B particles were then dried and observed with a transmission electron microscope (TEM). The individual nanoparticles were found to have an average radius of 4nm, suggesting that the large particles observed with the optical microscope are clumps of these nanoparticles.

4 Conclusion and Future Work

This research compared two different types of nano-oils and analyzed results from multiple tests to determine the effects of these oils on internal combustion engines. The effects of nanoparticle-enhanced oils on engines were examined by assessing the fuel efficiency, temperature, and vibration data an Auxiliary Power Unit and a 5.5 HP petrol engine. The oils were also characterized using viscosity and microscopy.

Batch A consists of diamond nanoparticles suspended in AeroShell 560 oil. The use of this oil resulted in a lower oil temperature during testing on the intermediate gearbox of the Experimental Drive Train but did not significantly affect oil temperature in the APU. It provided some improvement in fuel efficiency of the APU while greatly reducing vibration. These results suggest that Batch A does provide some benefits over the base oil.

Batch B contains zinc sulfide, boron nitride, and graphene nano particles. It provided greater temperature reduction compared to Batch A or conventional oils, but it resulted in a much higher oil temperature in the APU. While temperature greatly increased in the APU, vibration was substantially reduced in the APU and Small Engine. The use of Batch B also resulted in the highest fuel efficiency, indicating that the increased APU oil temperature is most likely not caused by an increase in friction. The increase in APU oil temperature may be due to the increased rate of heat transfer from the combustor to the oil and oil filter clogging.

Both nano-oils provided thermal and lubricating benefitsto the internal combustion engines. Although present formulations of the oils did not provide an exceptionally large increase in fuel efficiency, the results are promising and even a slight increase can provide substantial cumulative fuel cost savings. The reduction in vibration can reduce component failures, which could reduce maintenance requirements and result in additional cost savings.

Batch B oil clogged the APU oil filter due to the aggregation of nanoparticles within the oil sample. To ensure the durability of combustion engines using nano-oils, such clogging problems need to be resolved. Future work should focus on improving the composition of nanoparticle-enhanced oils to eliminate filter clogging problems and optimize vibration and temperature reduction benefits in combustion engines.

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Part IV
Electronics and Communication Technologies

Helicopter Main Gearbox Bearing Defect Identification based on Vibration Signal

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Abstract. Helicopter main gearbox (MGB) is one of the critical parts to ensure safety flight. The healthy condition of MGB is usually monitored by vibration and temperature sensors in helicopter Health and Usage Monitoring Systems (HUMS). Vibration sensors are mounted on the MGB case to avoid complex wiring inside the confined space of MGB. However, defects related signatures might be severely contaminated by background noise resulting from variable transmission paths from the defects to the receiving externally mounted vibration sensors. In this paper, the empirical mode decomposition (EMD) scheme was utilized to attract bearing defect related signature from external mounted vibration sensors. The EMD decomposes vibration signal into a number of intrinsic mode functions (IMFs) for subsequent envelope analysis. The analysis result shows the efficacy of the EMD scheme in detecting the bearing fault signatures from vibration signal.

Keywords: Helicopter main gear box; Condition monitoring; Fault diagnosis; Empirical mode decomposition

1 Introduction

Helicopter main gearbox (MGB) converts high rotation speed gas turbines input to low speed, high torque to drive main rotor blades and related to subsystems, e.g. lubrication and generator. MGB suffers from high temperature and stress resulting from a significant amount of frictional heat generated within MGB. Unlike jet aircraft, helicopter does not have redundant transmission system and hence the malfunction of the MGB can cause serious disaster. Although Health and Usage Monitoring Systems (HUMS) has been widely installed in helicopters to monitor the operational condition of critical parts, there are still several incident reports as a result of undetected faults of MGB (Department for Transport, 2011).

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Nomenclature

f_{ORD}	outer race defect frequency
f_{IRD}	inner race defect frequency
N	number of rollers
S	planet gear speed
d	diameter of roller
D	pitch diameter
α	nominal contact angle

The one of the major reasons is that sensors are usually installed on casing to avoid complex wiring within MGB. The indirect measurement could not provide accurate information since the signal might be significantly attenuated and/or contaminated. To address this issue, wireless transmission and advanced signal processing methods have been proposed in literature. A wireless helicopter MGB condition monitoring system has been design by Mba and colleagues (Elasha et al., 2015). In the system, acoustic emission (AE) sensor was attached on the planetary gears to avoid signal attenuation and contamination. AE signal was wirelessly transmitted by two coils, moving coil and stationary coil. The bearing outer race defect (ORD) frequency and its harmonic were successfully detected at the cost of additional hardware.

The typical wear-out or defect of components might result in the increased vibration amplitude and appearance of feature frequencies. Therefore, vibration sensors have been well developed and exploited for the purpose of machinery health monitoring. Many diagnosis approaches are proposed to detect faults related frequencies under the challenge of strong background noise. The envelope analysis has been proven to be a powerful tool for detecting bearings and gearboxes defects (Wang, 2001; Randall and Antoni, 2011). Faults can be inspected by identifying frequencies of the impacts, which results from defects excited resonance. In this method, a band-pass filter has to be utilized to obtain envelope signal. The selection of central frequency and frequency interval has a big impact on diagnosis results. Huang et al. proposed an iterative method, the empirical mode decomposition (EMD) scheme, which can decompose a multi-component signal into a number of intrinsic mode functions (IMFs) (Huang et al., 2015). Each IMF represents a mono-component function versus time. The EMD scheme has gained popularity for dealing non-linear and non-stationary signals in many fields, such as acoustic, biological, ocean, earthquake, climate and faults diagnosis (Huang and Shen, 2011).

The aim of this paper is to use available vibration signal to detect MGB faults using EMD. Since vibration sensors are already placed at key locations to monitor the operational condition in the current HUMS, there is no need of additional hardware. The remaining paper is organized as follows. Section II describes the experiment rig. Experimental results and EMD scheme are discussed in Section III. The findings of the study are concluded in Section IV.

2 Experimental Rig

A CS29 Category 'A' SA 330 Puma helicopter MGB was mounted on test bench with accelerometers (PCB 352C03, sensitivity of 10 mV/g) attached to the case of the gearbox, as shown in Fig. 1(a). The locations of accelerometers are replicable with HUMS setup. The accelerometers were connected to a NI cDaq 9188-XT data acquisition chassis and signals were acquired at 51.2 kHz sampling rate.

The MGB consists of five reduction gear modules (RGMs), left hand (LH) and right hand (RH) forward (Fwd) RGMs, after (Aft) RGM, main RGM and 2-stage epicyclic (Epi) RGM, as shown in Fig. 1(b). The defect was seeded on one of the planetary gears bearing of the second epicyclic stage, which is shown in Fig. 2(a). The slightly damage was simulated by machining a rectangular slot of 10 mm wide and 0.3 mm deep across the bearing outer race, as shown in Fig. 2(b). Fig. 2(c) shows the natural spalling around half of the circumference in the inner race.

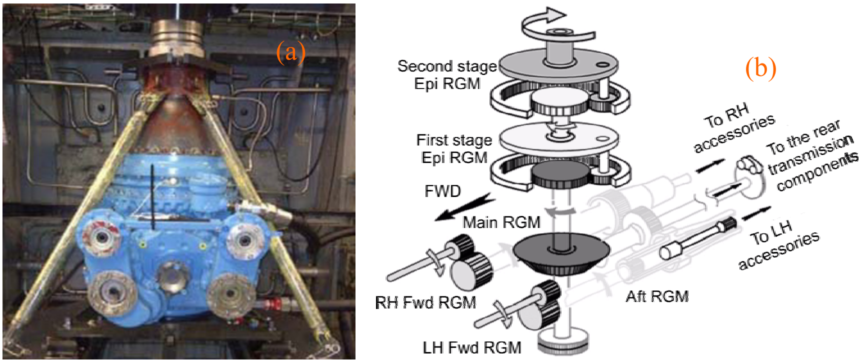

Fig. 1. (a) MGB mounted on test bench; (b) The sketch of helicopter MGB internal parts

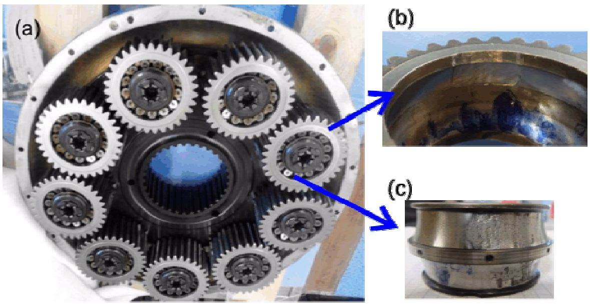

Fig. 2. (a) Second stage epicyclic gears; (b) Slot across the bearing outer race; (c) Inner race natural spalling

3 Experimental Results and Discussion

The experiment was conducted under 110% of maximum takeoff power (1760 kW) and rotor speed of 265 rpm. The equal input torque of LH and RH Fwd RGMs is 368 Nm. The bearing outer race defect (ORD) frequency f_{ORD} and inner race defect (IRD) frequency f_{IRD} can be calculated using the standard textbook equations

$$f_{ORD} = \frac{N}{2}\frac{S}{60}\left(1 - \frac{d}{D}\cos\alpha\right) \quad (1)$$

$$f_{IRD} = \frac{N}{2}\frac{S}{60}\left(1 + \frac{d}{D}\cos\alpha\right) \quad (2)$$

where N = 13 is the number of rollers, S = 1119 rpm is planet gear speed of the second stage Epi RGM, d=12.5 mm is the diameter of roller, D = 63.65 mm is the pitch diameter and α = 0 is the nominal contact angle. The calculated f_{ORD} and f_{IRD} are equal to 97.42 Hz and 143.96 Hz, respectively.

The recorded vibration signal with the largest amplitude was utilized to conduct signal processing. Fig. 3(a) and (b) show the recorded vibration signal in time and frequency domain, respectively. The frequency domain was obtained by using fast Fourier transform (FFT). In the zoomed in picture of Fig. 3(b), there was not obvious frequency component around the ORD frequency of 97.42 Hz. The frequency component was masked by the background noise. Since the interested frequency components are located in the low frequency band, a low-pass filter is utilized to remove high frequency components above 1 kHz. Then, the filtered signal was decomposed to several IMFs using EMD scheme.

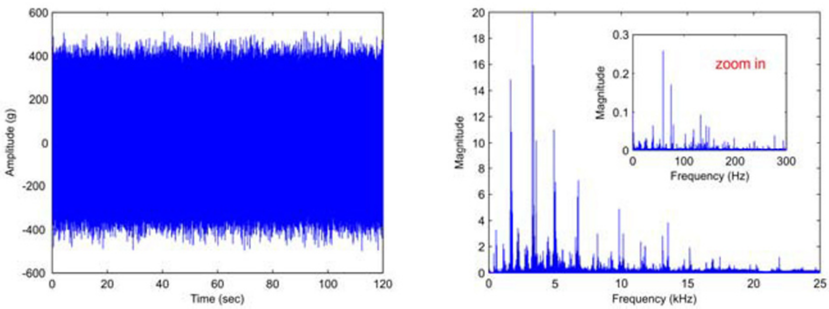

Fig. 3. Vibration data from fault bearing of the second epicyclic stage in (a) time domain and (b) freuqency domain

The EMD scheme is able to decompose non-linear and non-stationary data in to IMFs. Each IMF must satisfy two requirements (Huang et al., 2015): (1) In the whole data set, the number of extrema and the number of zero-crossings must either be equal or differ at most by one; (2) At any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is zero. This definition ensures a well-behaved Hilbert transform of the IMF.

The essential of EMD is to identify the intrinsic oscillatory modes by their characteristic time scales in the data empirically and then decompose the data accordingly (Huang et al., 2015). The decomposition procedure is a shifting process, which serves two purposes, to eliminate riding waves and to make the wave-profiles more symmetric. The shifting process is briefly described as follows

(1). Identify all local extrema in the test data $X(t)$.

(2). Connect all the local maxima by a cubic spline line as the upper envelope $U(t)$.

(3). Use the same procedure for the local minima to produce the lower envelope $L(t)$.

(4). Compute the local mean $M(t) = [U(t) + L(t)]/2$.

(5). Subtract $M(t)$ from $X(t)$, i.e. $X(t) - M(t) = h_1(t)$. If $h_1(t)$ satisfies the requirements of IMF, $h_1(t)$ is recorded as $c_1(t)$.

(6). By repeating the shifting process, $X(t)$ can be decomposed into N IMFs and a residue, $r(t)$, i.e.

$$X(t) = \sum_{i=1}^{n} c_i + r_n \tag{3}$$

The shifting process has to be iterated several times until reaches stop criteria, i.e. the component c_n or the residue r_n become too small.

Fig. 4 show the waveform of deposed IMFs 1-8 computed by EMD. The corresponding spectra of IMFs are shown Fig. 5. These figures only plot 8 IMFs because the low frequency IMFs are less interested in this study, which are neglected. The feature frequencies f_{ORD} of outer race defect and f_{IRD} are clearly characterized in IMF3 and IMF4 of Fig. 5.

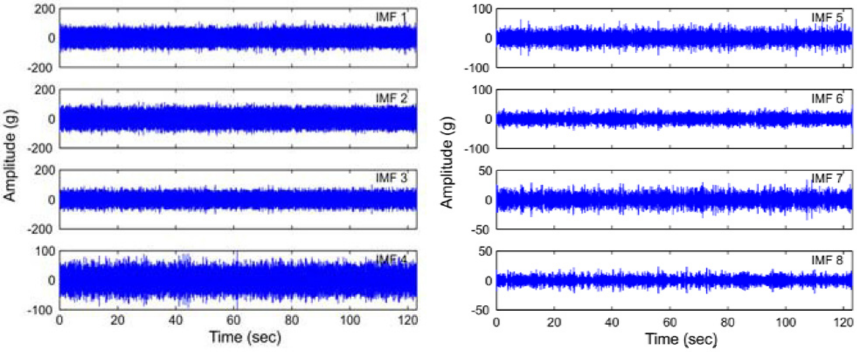

Fig. 4. The calculated IFMs 1-8.

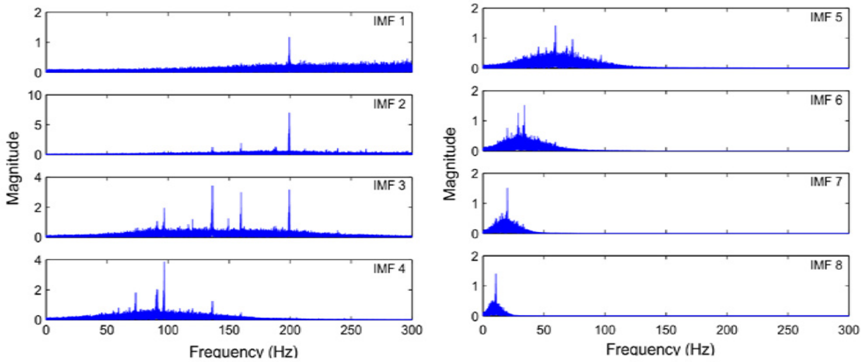

Fig. 5. The Fourier spectra of calcuated IFMs 1-8.

4 Conclusion

In the study, vibration signal was utilized to detect bearing outer and inner race defects of a planetary gear bearing of the second epicyclic stage in a helicopter MGB. Since the vibration signals were recorded by vibration sensors attached on the case of a helicopter main gearbox, the feature frequencies were marked by background noise in the vibration signal frequency spectrum obtained using standard FFT. After filtered by low-pass filter, the vibration signal was decomposed to IMFs using EMD scheme. The feature frequencies f_{ORD} of outer race defect and f_{IRD} were clearly were observed in Fourier spectra of IMFs. It has been shown the effectiveness of EMD in characterizing features frequencies.

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Wireless Acoustic Emission Transmission System Designed for Fault Detection of Rotating Machine

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Abstract. Acoustic Emission (AE) has been adopted widely in structural health monitoring of buildings, walls, bridges, and has shown great potentials in incipient rotating machine fault detection [1, 2]. However, one inevitable problem that hinders AE of being practically applied in rotating machine fault detection is the transmission of AE signal inside the machine, as AE signal generally comprises high frequency components of typically 100kHz to 1MHz which will require transmission system to have extremely high data-rate for real-time monitoring. Traditional digital wireless system, for instance, Wi-Fi or Bluetooth, cannot satisfy the requirement. This paper addresses the issue of wireless AE transmission for rotating machine, with a modified analogue AE wireless transmission system. Piezoelectric wafer active sensor (PWAS), a lab-crafted miniature sensor was adopted to fulfill the need of small system.

Keywords: *Acoustic Emission, Analogue Wireless Transmission, PWAS Sensor*

1 Introduction

Acoustic Emission is generally described as transient elastic wave that generated from deformation or damage on the surface or within the material. It has been adopted in structural health monitoring due to the capabilities of monitoring internal incipient cracks of walls. In terms of rotating machine, AE sources are coming from gear meshing, bearing rolling, shaft rotating and all the other contacts between components which have relative motions. Defects such as gear tooth cracks, bearing race pitting can also significantly alter the waveform of AE signals so that incipient fault detection is theoretically feasible. Research conducted by Abdullah M. Al-Ghamd [3] and David Mba [2] has shown that AE can be adopted as effective method for bearing fault detection, with unique advantage of estimating defect size and monitoring fault progression. Mathew *et. al.* [4] has applied AE inside helicopter main gearbox as mean of detecting bearing faults, and demonstrated promising results.

However, problems exist that prevent AE from being recognised as mainstream method for rotating machine health monitoring and fault detection. For starters, in order to get the best of AE's capability to react to incipient defect, AE sensor should

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be attached as close as possible near monitored rotating components, such that the AE signals generated from contacts of defects against rolling or meshing surfaces will not be attenuated too much by complex transmission path. Wireless transmission is hence mandatory, which is challenged by the inherent feature of AE signal being valid only in high frequency range. Typically, AE sensor reacts to excitations and generates signals of 100kHz to 1MHz. Traditional digital wireless system can hardly handle real-time transmission of such high frequency contents. Even for high speed protocol such as Wi-Fi, the task can be cumbersome, considering the fact that AE signal sampled at 5MHz combined with 12bit ADC could possibly require a system of handling 60Mbps for real time transmission. Grosse and Glaser [5, 6] developed wireless sensor network for AE system, Mistras Company offers commercial AE wireless monitoring system, but they all targeted off-line transmission and lower frequency range of AE signal. Space consuming of such system and AE sensors could also be an obstacle, as large system and sensor potentially endanger rotating machine if installed at rotating components.

Zahedi and Huang [7, 8] designed an interrogation-based analogue AE wireless system with commercially available components, which can transfer AE analogue waveform directly to overcome the shortcomings mentioned above. A lab-crafted AE sensor, namely PWAS is adopted for its miniature feature and reliable response. The system diagram is shown in Fig 1, it is a combination of two parts: Signal Interrogation Unit (SIU) and Sensor part. A high frequency 2.4GHz signal is separated to two paths, one is sent as Interrogation signal through SIU transmitter antenna after amplifying for signal modulation, the other one is sent to down-converting mixer for signal demodulation. In the sensor part, AE signal will be firstly buffered by voltage follower to compensate for high impedance of PWAS sensor, then mixed with the interrogation signal from SIU Transmitter antenna, and finally sent through the patch antenna at output port of the mixer. SIU receiver antenna will be tuned to receive the mixed signal, after band-pass and low-noise amplification, this signal will be demodulated using the same interrogation signal to recover the AE Signal. The process of digitalisation and cable transfer will then be undertaken.

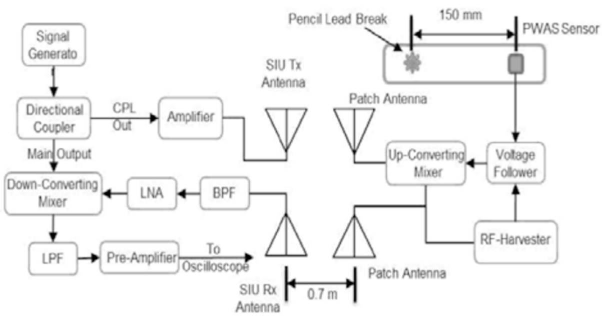

Fig 1 Analogue AE wireless transmission system [8]

2 Test of Analogue AE Transmission System

Inspired by Zahedi's design, such system was set up first, several tests were then carried out to firstly validate the system's ability of wireless signal transmission, followed by testing the system's performance regarding antenna angle changes to simulate rotating condition. Pencil lead breaks were adopted as excitations of AE source. A commercial WD AE sensor was adopted as comparison and connected directly to 2/4/6 pre-amplifier and data card using cable. Both WD sensor and PWAS sensor were attached to a metal surface, and a pencil lead break (PLB) was performed at their middle point to excite a AE signal. Both signals were sampled at 4MHz, pre-amplified by 40dB and band passed between 100kHz and1200kHz. Signal trigger level was set to 45 to filter ambient noises.

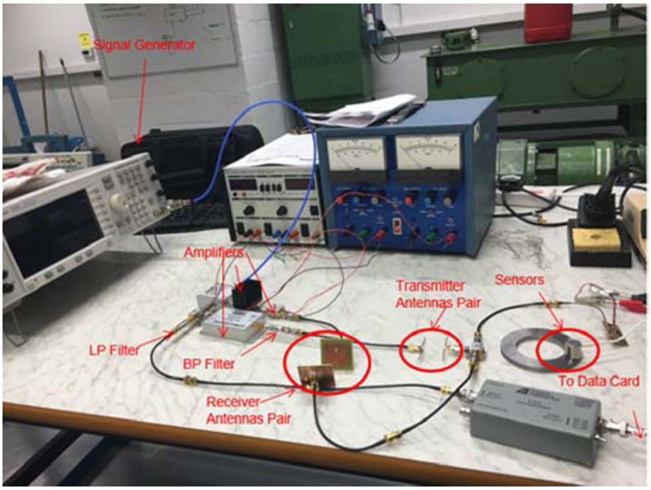

Fig 2 Analogue AE wireless transmission system set up

The result shown in Fig 3 suggests that, wireless AE signal has similar frequency content and time-frequency response. The fact that wireless system can receive reactions from excitation means AE signal can be transmitted wirelessly through the designed system. The differences of response amplitude and envelope are due to amplifications and sensor types. In addition, later angle test with one pair of antennas fixed showed that the response of wireless signal remained flat in approximately 30° angle range. With high sampling frequency of 5MHz, considering rotating machine speed of hundreds rpm, enough points will be collected within the time of rotating component spinning for 30°.

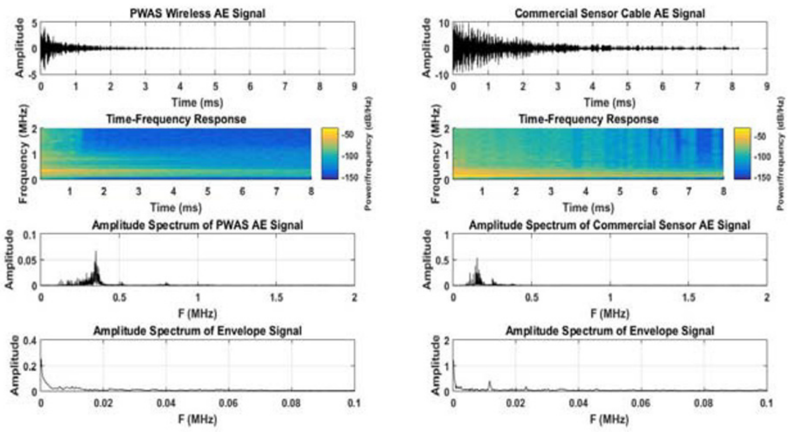

Fig 3 Comparisons of pencil lead break test of wireless signal and cabled signal

3 Test of Modified System for Rotating Machine

However, such system was developed for long range transmission, thus miniature design was excluded when chose system components and antennas. In addition, this system contains two pair of antennas, which adds more uncertainties when the transmitter part is rotating with the machine. To address these issues, a modified miniature system with only one pair of antenna is proposed. The schematic diagram is depicted in Fig 4.

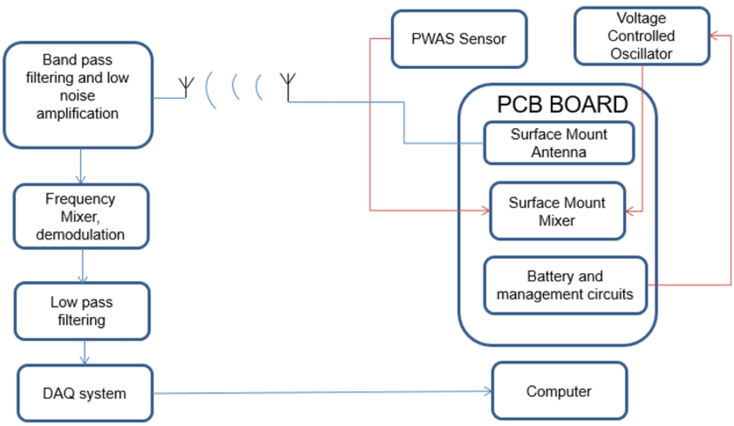

Fig 4 Schematic diagram of modified wireless transmission system

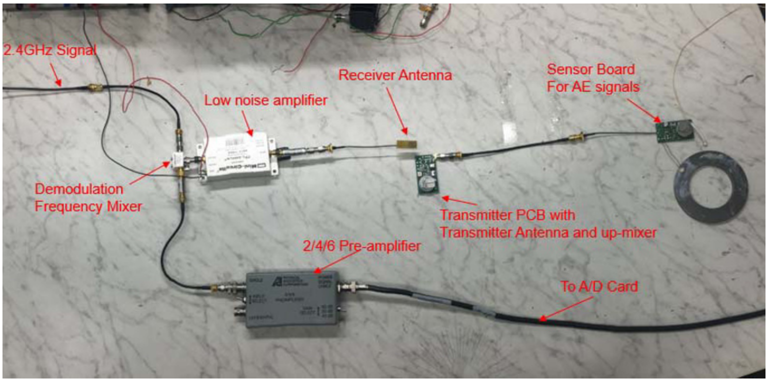

Fig 5 Modified analogue AE wireless transmission system

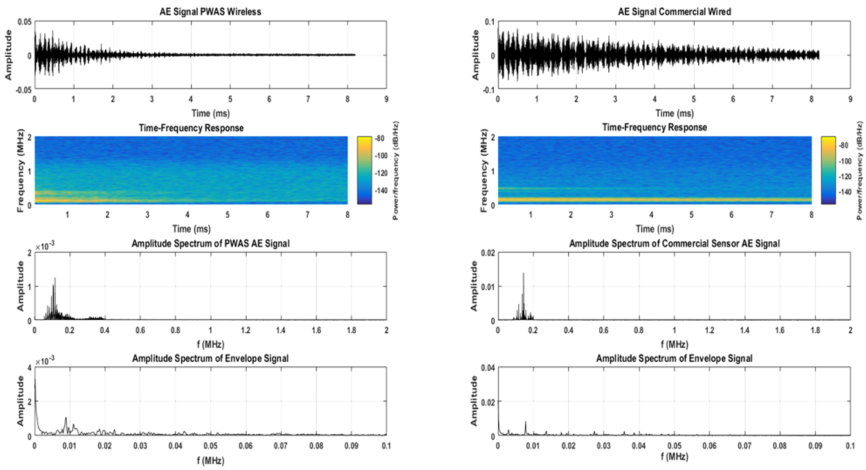

Fig 6 Pencil lead break test results of modified system

Two PCB are designed, of which one contains PWAS sensor and voltage follower for sensor buffer, amplifier selection is TLV 2781. The other board acts as transmitter that contains a voltage-controlled oscillator MAX 2750, surface mount frequency mixer SIM-73L+, and surface amount 2.4GHz button antenna. Both boards have embedded 3V battery and power management circuits to minimise power consumption. Voltage controlled oscillator generates 2.4GHz carrier signal, which then is mixed with IF signal from PWAS sensor. Up-mixed signal is transmitted wirelessly by surface amount antenna, and received at the receiver end. The processes after are the same with original design of two-antenna system. Fig 5 demonstrates modified analogue AE wireless transmission system set up. Transmitter part which will be installed at rotating components now comprises of two PCB boards and one antenna pair.

Same pencil lead break test was performed at modified one antenna pair system. The results in Fig 6 from test with modified AE wireless transmission system have demonstrated better and more reliable results. compared with result in Fig 3, the signal-to-noise ratios of wireless signal in Fig 6 is visually improved. Examining processed results, wireless AE system picks up frequency contents that are similar to that of cabled commercial sensor system. Their envelopes are depicted with parallel pattern. As obviously noted, test results showed that the modified system reacts fast to excitations, and envelope of wireless AE signal has demonstrated anticipated response similar to cable-transferred signal.

4 Conclusions

A wireless AE transmission system specifically targeting application of AE techniques in rotating machines is proposed. Two-antenna pair system was tested with large antennas and different antenna angles to validate system effectiveness and operational angles; improvements of such system have been made, thus modified system with one pair antennas can potentially be fit inside rotating machine such as gearboxes. Bench tests have shown promising results, which indicate that such system can pick up AE signals when excited, and transmit AE signal with proper quality. Picking AE event correctly is crucial for application of fault detection when using processing method such as envelope analysis. Future work is testing modified system inside commercial helicopter main gearbox, and validating system's performance when working under harsh condition inside noisy operational gearbox.

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