Life-cycle Cost Strategies for Harbors – A Case Study

Sofia Lingegård, Mattias Lindahl and Andreas Syberg

Original Publication:

Sofia Lingegård, Mattias Lindahl and Andreas Syberg, Life-cycle Cost Strategies for Harbors – A Case Study, 2015, Procedia CIRP, (Vol. 30), 317-322.
http://dx.doi.org/10.1016/j.procir.2015.02.136

Sofia Lingegård, Mattias Lindahl, Andreas Syberg, Life-cycle Cost Strategies for Harbors – A Case Study, Procedia CIRP, Volume 30, 2015, Pages 317-322, ISSN 2212-8271

Life-cycle cost strategies for harbors – a case study

Sofia Lingegård[a,b,*], Mattias Lindahl[a] and Andreas Syberg

[a]*Linköping University, Department of Management and Engineering, Environmental Techonology and Mangement, 581 83 Linköping, Sweden*
[b]*Pontarius AB, Box 1023, 101 38 Stockholm*

Abstract

This paper discusses maintenance strategies for large technical systems with long life-cycles and critical availability needs. The use of sea freight is rapidly increasing, and thereby the use of container harbors as well. The case of Gothenburg harbor in Sweden is used to discuss appropriate construction and maintenance strategies focusing on availability. Investment costs, operational costs and societal costs are discussed along with environmental impact considerations. Different aspects and considerations affecting costs are also discussed, such as pay-back time and external uncertainties. The paper is based on an extensive literature review as well as interviews with harbor personnel.

Keywords: life-cycle cost, maintenance strategies, long-term contracts, availability

1. Introduction

Large infrastructure investments are needed in the coming years, but it is important to ensure that this capital is used in an effective and efficient way. It has been estimated that the total investment need in the world can be reduced by 40% with e.g. better planning and maximal use of existing infrastructure resources [1]. One investment area that is increasing rapidly is that of maritime shipping, which accounts for two-thirds of the total goods trading in the world; maritime container transport, in fact, is growing by 10% per year [2]. The increasing trend for container harbors is shown in Fig. 1.

This implies demand for efficient logistics and management, and thereby availability of the container terminal. To provide logistics services in an efficient way the use and maintenance of the container terminal surface is extremely important, and especially the strategy to keep the availability high.

It is therefore relevant to build as durable as possible to reduce the need for reconstruction and maintenance, especially considering the long life-cycles for many large technical systems, e.g. container harbor infrastructure.

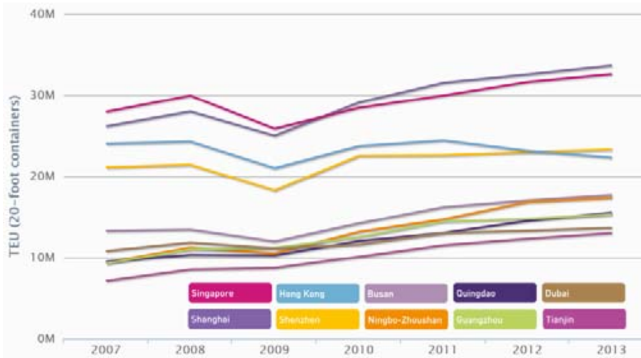

Fig. 1: Twenty-foot equivalent unit container figures for the 10 largest container harbors in the world 2007-2013 [3].

Previous research states that it is in the design phase where materials are selected, and where most of the environmental impacts are locked into the product [4]. Therefore, business models, e.g. product service systems (PSS), using a life-cycle perspective where both construction and maintenance of the infrastructure are considered in the design phase, could be useful for industry (see e.g. Tukker and Tischner [5] and Mont [6]). Furthermore, there is a need to construct and maintain the infrastructure of container harbors in such a way that the availability is optimal for the systems, since their aim is to provide possibilities for logistics.

There are many studies published regarding optimization of operations, planning and logistics in harbors [7]. However, life-cycle cost analysis is relatively new for maintenance in harbors.

This paper's objective is to highlight maintenance strategies for large technical systems with long life-cycles and critical availability needs. Parameters such as cost drivers and their interaction are discussed, as well as different options that need to be considered and the uncertainties involved.

In Sweden, maritime shipping accounted for 55% of exported goods in 2013 [8]. The Gothenburg harbor is the largest container harbor in Sweden, and will be used as a case in this paper.

2. Methodology

This paper is based on a summary of an extensive literature review as well as interviews with harbor-related respondents. Life-cycle cost (LCC) analysis is relatively new for maintenance in harbors, and little has been published in this area. For road construction and maintenance, more has been published regarding LCC and construction, use, maintenance and degradation. Similar perspectives have been developed within the airport area [9]. Both roads and airports have similar characteristics as harbors, i.e. being large technical systems where availability is crucial. A case study of Gothenburg harbor in Sweden is used to discuss the different aspects, parameters and considerations important to make life-cycle decisions for these types of large technical systems.

An interview study was performed with respondents from the largest harbor in Sweden, Gothenburg harbor, listed in Table 1. Gothenburg harbor owns the infrastructure, but the reinvestments and maintenance are performed by APM Terminals. In addition, an external consultant is involved in the maintenance work. Furthermore, documents from the harbor were used as background information.

Table 1: Respondents in the interview study.

Respondents	Position
Respondent 1	Infrastructure Manager, Gothenburg Harbor
Respondent 2	Infrastructure Manager, APM Terminals
Respondent 3	Business Controller, APM Terminals
Respondent 4	Business Area Manager, Seaport & Roads, Pontarius

3. The Case of Gothenburg Harbor

The organizational structures in harbors differ. The owner of the harbor can also be the operator, or delegate this task to a private company, while sometimes the transport company is in charge of the operations [10]. Gothenburg harbor owns the infrastructure, but the reinvestments and maintenance in the container harbor are performed by APM Terminals, one of the world's largest port and terminal operators [11].

The 80 hectare container harbor includes 1.8 kilometers of quays with 10 berths, railway tracks, eight container cranes and 40 straddle carriers, among other things [3]. The container harbor has over 20 visits each week by around 15 shipping lines, and the figures for 2013 were 858,000 containers (Twenty-foot Equivalent Unit (TEU)) (see Fig. 2), 557,000 ro/ro units, 163,000 new cars, 1.69 million passengers, 20.4 million tons of oil, and 38.9 million tons of freight [3]. This can be compared with Rotterdam, the largest container harbor in Europe, with 11.6 million containers in 2013 [3].

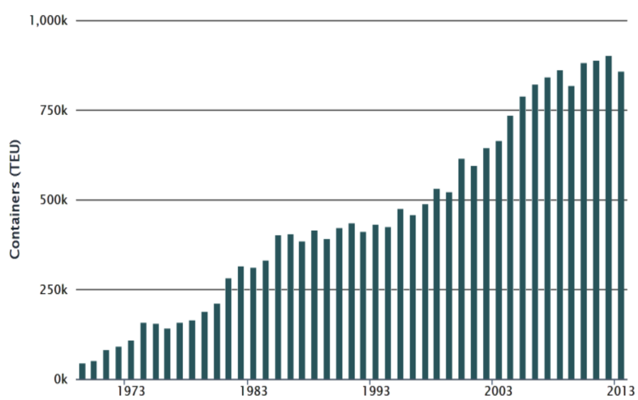

Fig. 2. Twenty-foot equivalent unit container figures for the port of Gothenburg [3].

The terminal surface is normally divided into several different parks, depending on their use, and within these parks import, export and empty containers are separated [7]. Fig. 2 shows an overview of the container terminal in Gothenburg harbor.

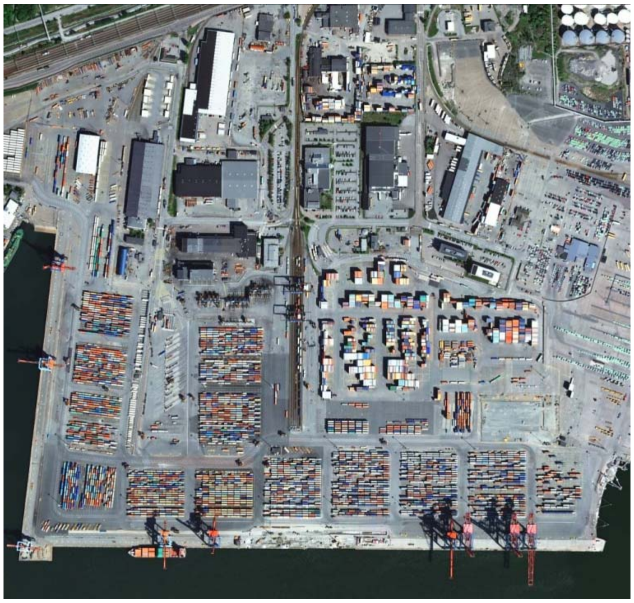

Fig 2. Overview of the container harbor in Gothenburg [12].

4. APM Terminals

APM Terminals was established in 2001 as an independent terminal operating company within Maersk Group, a Danish business conglomerate with more than 89,000 employees in more than 135 countries.

Today, APM Terminals is an international container terminal operating company headquartered in The Hague, Netherlands [13]. With its 20,000 employees in 63 countries, it is one of the world's largest port and terminal operators as well as a provider of cargo support and container inland services, and is the largest port and terminal operating company in terms of overall geographic scope [13]. Its revenue in 2013 was USD $4.33 billion, and it handled 36.3 million TEUs, whereof 30% were in Europe [13].

5. The Long-Term Contract

APM Terminals has a 25-year contract including the operations and maintenance of the container harbor. The residual value must be equivalent to the value when the contract started. The contract has a 70% fixed part, while 30% is volume-dependent. APM Terminals is in charge of all the contracts with the shipping lines, while the marketing for the container harbor is a joint effort.

The harbor provides the quays, basins and channels, while APM Terminals is responsible for the surface area and other facilities above ground, such as buildings and the railways. Anything below the pavement surface is the responsibility of the harbor.

6. Parameters Affecting the Life-Cycle Cost

Langdon [14], in line with ISO 15686-5 [15], defines the term LCC as all the relevant costs for an asset during its life-cycle, within defined system boundaries.

The Federal Highway Administration [16] and Walls and Smith [17] use the term LCC analysis to compare and assess different alternatives for a project. This includes all costs from initial capital cost, operational and maintenance costs as well as end-of-life cost. This can further be divided into owner and user costs [17].

The length of period analyzed can be determined in regard to the life-cycle of the asset, the length of the project, the economic or financial terms ; it can also be adapted to maintenance cycles. A longer period of analysis includes more uncertainties and risks, such as inflation and future demand, and is therefore more difficult to assess [14]. To adjust for different lengths in the analytical period for different options, a residual value can be included to account for the additional operational time [18].

The different costs identified are broken down and classified into different types and according to when they arise [14]. For roads, costs are divided into agency costs that arise when building and maintaining the road, and user costs for those travelling with vehicles [17]. For airports a similar split in costs is used, focusing on direct/owner costs and indirect/user costs [9]. Furthermore, societal costs as well as environmental costs can be added [18].

Around 10 years ago the maintenance of the container harbor surfaces was reviewed. Prior to this the surfaces were re-paved every second year, changing the top layer, something which was very costly. The surfaces were not dimensioned for the forces caused by the operational equipment used, due to a new type of equipment that was not in use when the surface was constructed.

To redo the whole surface was expensive, and it was calculated that an 8-10 year cycle in the maintenance was needed for a reinvestment to be profitable.

From the literature study as well as the interviews the following parameters were identified as the most important in terms of cost driving and cost carriers, as seen in Table 2.

6.1. Societal Costs

Societal costs are costs that society as a whole has to carry, and most commonly they include accidents and environmental impact [18]. However, it is difficult to quantify these costs for a harbor [19]. Investments in a harbor often imply increased production and demand for capital, labor and business, which can provide economic benefits for the region [10]. Noise, pollution, and use of material and transports are examples of environmentally related issues. Environmental impact should be assessed by life-cycle assessment if it cannot be calculated in monetary value. In this article, the environmental impact will only be qualitatively assessed when discussing e.g. energy consumption for constructing a surface compared to the maintenance phase.

Table 2: The most important LCC parameters for the surface in a container harbor according to the literature and interviews.

Costs	Affected by
Surface construction and maintenance • Planning • Design • Testing of material • Construction costs (material and labor) • Maintenance costs (material and labor) • Residual value	• Material costs (volume + unit price) • General agreements set for 2-3 years with contractors • Length of analytical period
Operative costs • Cranes and carriers (initial cost, maintenance, fuel) • Transport costs related to the quality of the surface	• Freight volume • Capacity changes • Surface quality • Transport length in harbor
Indirect costs **Societal costs** **Environmental costs**	• Choices made for the direct and operative costs

6.2. Availability in a Harbor

Availability is important in the harbor, since it is a limited space and a hub for different types of transportation such as ships, trains and pickup trucks that have to be synched for an efficient flow of goods. Turnaround time of the ships is therefore a key parameter, and describes the time from arrival to departure for a ship. This is affected by the operations in the harbor and how the availability is managed on the surface, including container management and surface and equipment maintenance.

The factors affecting the operative costs are identified as transport distance, time and evenness of the surface. The evenness depends on the quality of the surface, while length of transport depends on the possibility to decrease the transport distance. Time can be defined as the increase in additional container transports and is therefore affected by increased transport speed, decreased transport distance and increased possibility to use the equipment.

7. Life-Cycle Cost Strategies for Harbor Surfaces

From the interviews it was obvious that there are several different options that must be weighed against each other to determine an optimal life-cycle strategy including the design, construction, maintenance and use perspectives.

Three different strategies are discussed below, as they are the most important regarding availability and resource use in the container harbor.

7.1. Flexibility in Use vs. Optimal Paving for Specific Use

The different parks in the container harbor are used in different ways: parks near the quays, transport areas, or areas for empty or full containers. The frequency of use normally depends on the closeness to the quays. Therefore, the purpose and frequency of use is important to determine, since this affects the maintenance cycles for the surfaces.

One way to manage the maintenance is to over-dimension the robustness of the surfaces. In this way, all the surfaces can be used for any purpose. Also, when maintaining one park there are always alternative ones to use. This creates flexibility in the harbor. On the one hand, this is a very expensive strategy, which can only be motivated if the probability of large changes in need is significant. On the other hand, the need for maintenance is probably lower for several of the parks.

The antipole to the over-dimension strategy is to adjust the pavement strategy depending on the use of the different parks. In this strategy, the parks are optimized according to the use planned for them. This means that the resources used, material and construction are optimized for this as well; hence, the initial cost is lower than for the over-dimension strategy. However, this is an inflexible approach since it limits the use of the areas for activities other than the ones they had been modified for.

These strategies can be mixed, where some parks are optimized for specific activities and needs while others are dimensioned for maximum usage. This all depends on the need and demand in the harbor, in this case the container harbor in Gothenburg.

APM Terminals, the party responsible for the maintenance and operations of the container harbor in Gothenburg, has to take these strategies into consideration. Since the harbor is responsible for everything below the pavement this could possibly cause problems for APM Terminals, since the quality of the surface very much depends on the quality of the foundation below. In general, the party that can best handle the risk should carry it to avoid high risk premiums (see e.g. Akintoye and MacLeod [20] and Barnes [21]). In this case, APM Terminals is also responsible for the wear of the surface, implying a possibility to assess future maintenance needs. A PSS provider with a large customer base can develop specialized skills for optimizing maintenance routines and thereby increase the availability (see e.g. Alonso-Rasgado and Thompson [22] and Toffel [23]). This is the case for APM Terminals, considering how many more harbors this organization is in charge of in the world.

Maintenance is realized during certain times, but could theoretically be done continuously during both day and night. This would result in increased labor cost, but reduce the time the park is closed and thereby increase availability in the harbor.

7.2. Economy of Scale vs. Availability During Maintenance

The maintenance can be accomplished by aggregating several parks and performing the maintenance on several at once. This creates economies of scale, both in terms of the machines needed and in the possibilities to obtain material at a lower cost when purchasing large quantities. Furthermore, the maintenance could be performed in a more efficient way when working with larger areas. This, however, would have a greater impact if the areas maintained had the same degree of pavement robustness.

A PSS provider that strives for availability and minimizing downtime on equipment produces products that are easy to maintain [24]. For APM Terminals, it would therefore make sense to maintain as large an area as possible to perform efficient maintenance. This, on the other hand, greatly affects the availability in the harbor, since a larger area will be closed. The equipment for transporting the containers would have to be driven longer distances and take detours, especially if the maintenance area is closed to the quays. This directly affects the transport costs as well as the potential turnaround for the ships. Since APM Terminals is also responsible for the operations in the harbor, the turnaround is of utmost priority.

Instead, maintenance could be performed on several smaller areas in the harbor. This affects the availability less, since it provides the possibility to use parts of the parks while other parts are maintained. However, this also results in less efficient maintenance due to machine and material costs as well as time factors. The cost for lost availability depends greatly on which area is closed, and as described before the parks closer to the quays are more critical for the availability.

7.3. Early vs. Late Maintenance in the Life-Cycle

Since availability is such a critical factor, maintenance has to be well timed. Tracks in the surface and damage caused by containers are factors that affect the need for maintenance. When the surface is worn down, this affects the operations. For instance, reduced quality of the surface affects the transport of the containers. The carriers have to drive with reduced speed, affecting the availability, and the tires are worn out faster, causing additional costs. Also, increased vibrations can cause issues related to the work environment which can affect the operations, and thereby the availability, due to sick leaves. Furthermore, late maintenance could result in unnecessary cost if the surface is so worn down the top layer has to be changed.

Early maintenance, that is shorter maintenance cycles, can be performed to avoid long closedowns of the parks. In this way, several shorter closedowns can be done since the maintenance needed is less severe than if maintenance is performed when the surface is totally out of use. However, it could be argued that the total potential of the surface is not fulfilled if the maintenance is performed too early.

Finding the breaking point for optimal maintenance is one of the major issues for the harbor. Here, APM Terminals has the advantage of serving many harbors and therefore having access to a large database of data regarding surface wear and maintenance cycles. Using this for optimized maintenance is in line with Alonso-Rasgado and Thompson [22] and Toffel [23] as a way to achieve good results in availability-based contracts.

In general, for surfaces it can be said that a low initial construction cost often implies shorter maintenance cycles. Therefore, this strategy is also more affected by the material prices, for example that of asphalt, which fluctuates with the oil price. A high initial cost, on the other hand, generally results in longer maintenance cycles.

Therefore, it is both the balance between the construction and maintenance costs, as well as the maintenance strategy, that have to be optimized in regard to the use of the surface.

8. Concluding Discussion

When discussing strategies for construction and maintenance it is important to consider the time period for the optimization. Is it the life-cycle of the facility, here the surface in the container harbor, or is it optimization during the contract period? The city of Gothenburg owns the harbor and therefore has a long-term perspective, while APM Terminals has a shorter contractual perspective. In this case, the contract is for 25 years, which has to be considered quite long. Nevertheless, these two actors could have different agendas which have to be taken into account. A long-term contract implies uncertainties that have to be taken into account in the design phase, and it is there where most of the cost impact of the life-cycle is determined [25]. However, the long life-cycle increases uncertainty, making it difficult to attain trustworthy data for a LCC [26]. Different choices made have different pay-back times, which is relevant in the discussion.

LCC methods normally assume that future data is available, which is then of limited value when there is high uncertainty, making options based on future costs and benefits in regard to uncertainty levels appropriate to use [26].

Additionally, if the societal costs are added to the discussion they are probably more evident for the owner of the harbor than for the private party. How can these costs be included in the assessment?

Different strategies have different impact on the availability. However, a temporary capacity reduction is only an income loss if there is a need for the capacity at that specific moment in time. In the same way, increased capacity is only an income if there is a demand for this capacity. This is also a factor to consider when choosing a strategy for construction and maintenance.

However, the main uncertainty in this case is the long-term perspective, which affects both the degradation of the surface and uncertainties in future demand. The uncertainty and thereby variability in values used for different factors is the reason why the causes of variability in the LCC model can have great impact on decision-making processes [26].

8.1. Further Research

The contractual agreement between the harbor and APM Terminals needs to be further investigated to understand the risk sharing between the parties. This is important, since the responsibility of APM Terminals is very much dependent on the foundation for the surface provided by the harbor.

Furthermore, it would be interesting to look further into the different options discussed in this paper and quantify them both in terms of life-cycle cost and life-cycle assessment. In this way, they could have a more direct input into decisions made about future maintenance in a harbour.

9. Acknowledgements

The authors would like to thank Gothenburg harbor and APM Terminals for making this study possible. The authors would also like to express special gratitude to Pontarius for their finance and active cooperation in the empirical research.

References

[1] Dobbs, R., Pohl, H., Lin, D., Mischke, J., Garemo, N., Hexter, J., Matzinger, S., Palter, R., and Nanavatty, R., Infrastructure productivity; How to save $1 trillion a year, 2013.

[2] Grossmann, D.H., Otto, D.A., Stiller, D.S., Wedemeier, J., Koller, C., Pflüger, W., and Roestel, A., Strategy 2030 - Maritime Trade and Transport Logistics, 2006.

[3] Gothenburg Harbor. portgot.epipro.se/en. 2014 [cited 2014 9th of January].

[4] Lewis, H., Gertsakis, J., Grant, T., Morelli, N., and Sweatman, A., Design + Environment - a global guide to designing greener goods, 2001, Sheffield, UK: Greenleaf Publishing Limited. 2001.

[5] Tukker, A. and Tischner, U., eds. New Business for Old Europe. Vol., Greenleaf Publishing: Sheffield. 2006.

[6] Mont, O., Innovative approaches to optimising design and use of durable consumer goods. International Journal of Product Development. 6(3). 2008; p. 227-250.

[7] Steenken, D., Voß, S., and Stahlbock, R., Container terminal operation and operations research - a classification and literature review. OR Spectrum. 26(1). 2004; p. 3-49.

[8] The Swedish Transport Administration, Förslag till nationell plan för transportsystemet 2014-2025 : remissversion 2013-06-14, 2013.

[9] ARA, Life Cycle Cost Analysis For Airport Pavements, Final report prepared for Airfield Asphalt Pavement Technology Program (AAPTP), 2011.

[10]Musso, E., Ferrari, C., and Benacchio, M., Port Investment: Profitability, Economic Impact and Financing. Research in Transportation Economics. 16(0). 2006; p. 171-218.

[11]APM terminals. www.apmterminals.com. 2015 [cited 2015 9th of January].

[12]Eniro. Gothenburg Harbour, http://kartor.eniro.se/?index=yp&id=14995708&query=g%C3%B6teborgs%20hamn. 2015 [cited 2015 10th of January].

[13]APM Terminals. Apmterminals.com. Fact Sheet Q1. 2015 [cited 2015 10th of January].

[14]Langdon, D., Life Cycle Costing (LCC) as a contribution to sustainable construction: a common methodology - final methodology, 2007.

[15]ISO 15686-5, Buildings and constructed assets - Service-life planning - Part 5: Life-cycle costing, International Organisation for Standardisation (ISO) 2008.

[16]Federal Highway Administration, Life-Cycle Cost Analysis Primer, Office of Asset ManagementWashington, DC., 2002.

[17]Walls, J. and Smith, M.R., Life-Cycle Cost Analysis in Pavement Design — Interim Technical Bulletin, Federal Highway Administration, Washington, DC. 1998.

[18]Ozbay, K., Parker, N.A., Jawad, D., and Hussain, S., Guidelines for Life Cycle Cost Analysis, Research Project Final Report. Report No: FHWA-NJ-2003-012 , New Jersey Department of Transportation, Trenton. 2003.

[19]Taneja, P., Aartsen, M.E., Annema, J.A., and Ligteringen, H. Investment appraisal for sustainable ports. in Infrastructure Systems and Services: Next Generation Infrastructure Systems for Eco-Cities (INFRA), 2010 Third International Conference on. 2010; p. 1-6.

[20]Akintoye, A.S. and MacLeod, M.J., Risk analysis and management in construction. International Journal of Project Management. 15(1). 1997; p. 31-38.

[21]Barnes, M., How to allocate risks in construction contracts. International Journal of Project Management. 1(1). 1983; p. 24-28.

[22]Alonso-Rasgado, T. and Thompson, G., A rapid design process for Total Care Product creation. Journal of Engineering Design. 17(6). 2006; p. 509 - 531.

[23]Toffel, W.M., Contracting for Servicizing, Harvard Business School: Boston 2008.

[24]Kindström, D. and Kowalkowski, C., Development of industrial service offerings: a process framework Journal of Service Management. 20(2). 2009; p. 156 - 172.

[25]Uher, T.E. and Toakley, A.R., Risk management in the conceptual phase of a project. International Journal of Project Management. 17(3). 1999; p. 161-169.

[26]Vennström, A., Olofsson, T., Fawcett, W., Dikbas, A., and Ergen, E., Determination and costing of sustainable construction projects : option based decision support, in CIB W78 2010: 27th International Conference - Applications of IT in the AEC Industry& Accelerating BIM Research: Cairo Egypt 2010.