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SUSTAINABLE RESILIENCE IN PROPERTY MAINTENANCE: ENCOUNTERING CHANGING WEATHER CONDITIONS

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ABSTRACT

Purpose: The purpose of the study is to develop a methodological approach for project management to integrate sustainability and resilience planning in property maintenance as an incremental strategy for upgrading existing properties to meet new standards for sustainable and climate resilient buildings.

Background: Current maintenance practice is focused on the technical standard of buildings, with little consideration of sustainability and resilience. There is a need to develop tools for incorporating sustainable resilience into maintenance planning.

Approach: The study is primarily theoretical, developing the concept of sustainable resilience for changing weather conditions

Results: The paper suggests a decision support methodology that quantifies sustainable resilience for the analytical stages of property maintenance planning.

Practical Implications: The methodology is generic and expected users are FM organisations with responsibility of property maintenance, and consultants offering property management planning as a service.

Research limitations: The methodology is conceptual and has not been tested. However the concept is to be further developed in dialogue between the authors, the Danish local authority Gentofte Properties and other potential users.

Originality/value: The paper suggests a new methodology to explicitly integrate sustainability and resilience planning in property maintenance planning.

Keywords: Sustainable FM, Climate adaptation, Guideline, Planned maintenance, Property management

1 INTRODUCTION

Every day property managers around the globe plan the maintenance tasks ahead of them, either as part of a periodic inspection and planning process, or as emergent maintenance because an acute problem has occurred. This paper investigates how opportunities for upgrading the existing building stock can be executed in a way that also includes the perspective of sustainable development and climate resilient cities in an integrated way. A building's resilience is a measure of how well a building continues to function during or after an event, and, if the function of the building has been affected, how fast the building can regain its function. Here we are primarily concerned with extreme weather events, but our general framework is applicable to other events, e.g. power failure. Climate resilience has received a significant increase in attention due to predictions that climate change will cause more extreme weather events (Beniston M. et al., 2007).

Climate adaptation and resilience is no longer only an issue at a political level but is also an emerging topic in the FM research literature (e.g. Warren 2010 and Carthey et al., 2009). However, in general, we believe that most of the maintenance and operation strategies in practice do not yet deal with climate change and the sustainability agenda, beyond simple energy savings. Those working with the conditions of current building stock do not consider the risk associated with changing climate.

Typically the maintenance and operation strategies are based on the current condition of the building stock and can be simplified into two types of maintenance: emergent or planned (Flores-Colen I. et al., 2010). The better the building owner knows the condition of his building stock, the easier for him/her it is to plan the cost of maintenance and repairs. In such a portfolio the budget for emergency cost is expected to be small and the planned maintenance cost budgets are distributed through a number of years so the owner is comfortable with his spending. Together with a repair plan, the owner can incorporate the upgrading of the building elements, which will reduce the maintenance or operational cost of the building in the future. However, even a well-managed building portfolio can be disturbed by extreme weather events, which increase emergent maintenance cost and possibly place the owner of the building in financial difficulty. To reduce the risk of unexpected costs, building owners must investigate cost effective options to adapt their properties to possible future environmental changes whose consequences are yet unknown. As Bosher et al., observed, "*Well-designed buildings, properly protected from the hazards associated with climate change, will be easier to sell or let and could also command higher prices. Opportunities are therefore available for organisations to position themselves as market leaders in the climate- related 'future-proofing' of buildings, thereby presenting a means of attracting new customers and gaining a competitive edge.*" (Bosher L. et al, 2007).

Numerous methods have been proposed for measuring both resilience and sustainability, separately. Often the investment needed to make a building more resilient or sustainable is not easy to express in monetary terms, which can then be compared with the investment. This is because many of definitions of resilience or sustainability are difficult to measure, and as such provide insufficient information with which to make investment decisions, as most investment decisions are determined by economic models such as return of investment. To address this issue we investigate a method of quantifying the sustainable resilience of buildings, which can be applied in a decision making process of everyday maintenance strategies. In this paper we discuss how risk management tools familiar to some building owners, facility manager, architects, and other decision makers, can be used to quantify resilience, and facilitate the decision process for selecting between remedial solutions with varying degrees of sustainability.

The paper has the following structure. In Section 2, we first review previous work on resilience, sustainability, and sustainable resilience. Section 3 then summarizes how risk management can and has been used to quantify resilience. Ultimately we see resilience and risks as two sides of the same coin: the higher the risk, the less resilient a building is. We then discuss how sustainable solutions can be incorporated into the risk framework through the economic concept of externalities. Section 4 provides an illustrative example of how the framework can be used. Finally Section 5 provides a discussion of future work

2 BACKGROUND

Resilience is becoming increasingly used in the context of climate change and adapting built environment. Most resilience studies on climate change have been undertaken by mapping threats such as the increased possibility of flooding, sea level rise or heat-waves (Beniston et al., 2007), (Biesbroek et al., 2010), (Bosher L. et al., 2007),(de Wilde et al., 2012), (Snow et al., 2011), investigating the vulnerability of a system to these threats (Guan 2012), (Camilleri et al., 2001), (Jentsch et al., 2008), or investigating how to increase a capacity to adapt (Lomas 2009).

2.1 Definition of Resilience

We are interested in resilience to extreme weather events, although the framework is applicable to other events as well. Given the possibility of an extreme weather event, e.g. a heat wave, resilience seeks to determine how well a building or system continues to function during and after the event. As such, we broadly follow the definition of Nelson that "*System resilience refers to the amount of change a system can undergo and still retain the same controls on function and structure …*" (Nelson et al., 2007), although we acknowledge a number of other possible definitions of resilience depending on various perspectives. (Manyena S.B., 2006), (Folke C. et al., 2002), (Bosher L. et al., 2007). (Carpenter S. et al., 2001; Christenson M. et al., 2006; Cole R.J., 1998; Cox R.A et al., 2014), (Holling C.S, 1996), (Pimm 1984)

While such measures are valuable, particularly in the context of understanding the ecology of a region, we believe such measures are of limited value in supporting the process to decide whether remedial action should be taken to improve a building's resilience. For example, knowing that a building is resilient to average daily temperatures of up to say 30C is useful, but any investment decision must also consider both the cost of failure when daily temperatures exceed 30C and the probability of such weather events occurring. The latter probability is necessary to arrive at an overall expected cost that can be directly used to prioritize investments. Assigning an economic cost to resilience can be handled using well-known risk measures, which are discussed in the next section. However, before doing so, we next discuss sustainability.

2.2 Definition of sutainability

The definition of sustainable development (SD) was defined by Brundtland Commission in 1987 as "development the meets the needs of the present without compromising the ability of future generations". This definition is often described as triple bottom line, because it considers ecological, economic and social consequences of development. According to this definition the environmental, social and economic needs are defined as equal and "*must deliver* *prosperity, environmental quality and social justice*" (Ding G.K.C., 2008). We argue, that the Brundtland definition is very broad, without a clear understanding of the limits of the natural cycle of a limited area. This definition of sustainability is difficult to quantify. To be able to quantify and measure sustainability we view sustainability as "the ability of our own human society to continue indefinitely within natural cycles of the earth" Baxter et al. (2010). By doing that we could identify the natural cycles of the limited geographical area, such as a country, a city, a company, a project or even a building.

As resilience can be quantified using risk analysis, similar the sustainability can be measured by quantifying a building's impact on environment. However the impact on environment is more difficult to quantify as some of metrics such as different greenhouse gasses (GHG) are quantitative and well defined and can be compared globally, and other impacts such as overall impact on environment can only be quantified qualitative by "awarding points for presence or absence of desirable features" (Cole R.J., 1998). Most of building sustainability assessments tools such as BREEAM, LEED or DGNB etc. are well defined tools for a specific type of building in specific geographical area and taking into account both qualitative and quantitative metrics (Ding G.K.C., 2008). Most of the building assessment tools are based on a scoring system, which is defined and weighted by either (i) all criteria's are weighted equally, or (ii) weighting coefficients were determined by questionnaire survey of users of the system such as designers, building owners, operators, and can be modified to suite the local conditions.

From the facility managers' perspective there is still missing a method to evaluate smaller refurbishment projects where only one or two components of the building are to be replaced as part of maintenance. In such projects the environmental impact should to be expressed in monetary terms to be able to feed in to the traditional Cost Benefit Analysis (CBA). The CBA is a well-respected tool where everything is converted into monetary terms and decisions are based on highest net value (Ding G.K.C., 2008). As we already discussed, the environmental impacts are not always possible to express in monetary values. We investigate how the environmental impacts can be included in CBA.

2.3 Definition of sustainable resilience

The idea of merging both sustainability as a mitigation option and resilience as the adaptation option has been suggested by (Mills E. et al., 2003), (Bosher L. et al., 2007) and (Camilleri M. et al., 2001), (Folke C. et al., 2002). However, the authors only discussed a need of coupling the sustainability and resilience without suggesting how to quantify them.

3 APPROACH

The study is primary theoretical as it draws on current literature on sustainability and resilience to develop the concept of sustainable resilience. However it builds on the example of property maintenance in the Danish Municipality Gentofte, and illustrates how Gentofte and other property managers can innovate their property maintenance planning practice to meet new political strategic goals of sustainable resilient properties.

Risk and resilience are seen as two sides of the same coin and therefore the developed guideline adopts a risk management approach. (Jones 2012) has a similar approach when suggesting a framework for risk assessment for extreme climate change challenges. The difference between Jones and this paper is primary that we integrate traditional building technical maintenance not only with extreme climate change risks, but also with the sustainability profile of the building.

This study could be done in a qualitative way to illustrate the line of thinking. But in order to meet the expressed need of measuring and quantifying engineering solutions to demonstrate a value and to allow multi-criteria comparisons of alternative solutions and total cost/value evaluations, we aim for quantifications of each indicator. We also assume an economist's perspective that facility managers are rational and base decisions on economic criteria, i.e. facility managers are asked to create as much value as possible out of a given budget.

The paper presents work in progress and is there for not fully developed in terms of suggesting specific measures for sustainable resilience.

3.1. Quantification of resilience

In summary the resilience can be measured by (i) defining most significant indicators, or (ii) using risk analysis. The risk (R) is defined as the expected consequences associated with a given activity (Faber M.H., 2012). Risk can be described by a function of probability (P_i) of an event, i, occurring, together with the consequence (C_i). If there are n possible events, then the risk is defined as

$$R = \sum_{i=1}^{n} P_i * C_i$$

From the facilities management point of view there are several advantages for using risk assessment for quantification of resilience:

a. To be able to calculate the risk assessment the object or system whose resilience we are investigating must be well defined: resilience of what, and resilience to what. Thus, to quantify the resilience of a building, we need to split the building as a system into different problem areas: for example if we are investigateing the resilience to overheating we are only looking into the indoor temperatures and not other parameters such as degradation of the external materials.
b. Be calculating the risk of failure it is possible to express the failure in monetarey terms. How much it will cost if the system will fail and how much it will cost to prevent that failure.

However the disadvantage of only taking the risk assessment into account is that the overall resilience of the building will be difficult to assess and the environmental impact of the proposed solution is not evaluated.

To be able to include the environmental impact of the solution we are also require to look at the sustainability assessment methods that are described below.

3.2 Quantification of sustainability

The quantification of sustainability of buildings can be measured by:

(i) Different sustainability indicators covering all 3 aspect of sustainability (ecological, economical and social) and are usually defined from project to project
(ii) Environmental assessment tools, which are based on the awarded points, and are weighted by the overall impact on buildings and is often a 5 level system, where 5 is the most desirable environmental performance of the building, The advantage of such system is that the evaluation of the building's environmental performance becomes

more comparable within the same scheme and within the regions. The disadvantage is that it does not take economic cost nor resilience into consideration (at least not directly)

(iii) Sustainability index where different alternative solutions can be calculated and compared to each other by including not only the economic cost of a solution but also the Benefit Cost Ratio (BCR), Energy Consumption (EC), External Benefits (EB) and Environmental Impact (EI). This has the advantage of considering economics but not resilience.

3.3 Quantification of sustainable resilience

The first attempt to quantify both the sustainability and resilience was proposed by Camilleri using Climate Change Sustainability Index (CCSI), (Camilleri M. et al., 2001). The author proposed to establish a scoring system rating from -2 to +5, where the scores are given based on Annual Exceedence Probability (AEP).

(iv) Climate change sustainability index, which rates a building's adaptation performance by using the probability of return of extreme event, which will affect the performance of the building. The method proposed ranking a building from -2 to 5 (where 0 represents no risk at present, but the risk is already occurring in the adjacent properties).

4 RESULTS

The focus of the paper is how to quantify sustainable resilience as input to maintenance planning. In the following we use risk and incorporate additional costs to non-sustainable solutions. These costs are often referred to as externalities within economics such as: carbon costs, water consumption, public relations etc. These costs allow a return on investment (ROI) to be calculated for both resilient and sustainable resilient solutions. The general approach is to define risk and introduce the basic concepts, e.g. probability of an event and cost of event and compare it with the expected cost of the maintenance project.

To illustrate the methodology we investigate how resilient a historical naturally ventilated building is to changing weather conditions. We restrict our investigation to only one changing parameter – external temperature and investigate the building's resilience, i.e. ability to maintain its function during the extreme high temperatures. We consider the spatial area of Denmark and the time periods of current climate, 2050 and 2100.

4.1 A 6 step approach to measuring sustainable resilience:

Given (i) a building and (ii) a disturbance, e.g. temperature

1. Determine the resilience of the building to temperature, i.e. at what temperature will the building's functions be compromised?
2. Determine the cost associated with the loss of building functionality.
3. Determine the probability of the event/disturbance occurring.
4. Apply risk analysis to determine the expected cost associated with the current resilience of the building, (existing conditions).
5. Determine cost of remedial solutions as well as period when the solution is required
6. Apply cost benefit analysis to select (or not) a solution

To incorporate sustainability, step 5 is expanded as following;

a) Determine capital and operating costs, as before
b) Determine direct/indirect ecological costs, e.g. carbon tax, etc.

c) Determine intangible costs to say, reputation
d) Add (a)-(c) to determine total cost, then go to Step 6

The steps for investigating sustainable resilience, described above, are used to illustrate the example below. The example investigates the resilience of a naturally ventilated building to heat waves in Denmark, as an illustration of the principles of the method.

Step 1 Determine the resilience of the building to temperature
The resilience of building stock depends on the type of extreme weather events, which will have different consequences. Increased temperature will reduce heating demand, but increase cooling demand and will increase the risk for overheating (Christenson et al. 2006) (Jentsch et al. 2008).

In the context of the risk of overheating in a naturally ventilated building, we define the Limit State Function (LST) as the event when the naturally ventilated building (i) fails to provide a comfortable thermal environment, which can result in loss of productivity, (ii) must be closed due to overheating, and (iii) becomes a risk to human life.

Table 1: The threshold for different LSF in naturally ventilated building

Stages of failure	**Internal temperature ^oC**
No impact (G_o)	21<t>25
Loss of productivity (G_1)	25<t>30
Loss of function (G_2)	30<t>32
Risk of mortality (G_3)	32<t

Step 2 Determine the cost associated with the loss of building functionality
The cost associated with the loss of buildings function will be different for different stages of failure G_1, G_2, G_3. The risk of mortality G_3 will not be discussed further as the building will be closed before the risk will occur. Therefore the risk of loss of function G2 will be expressed as the loss of function during periods where the external temperature exceeds 32^{o}C. The cost of productivity is most relevant for this case and is discussed in detail below.

A review of the literature investigating the relationship between indoor temperature and productivity is provided by (Seppanen et al. 2004), who observed a strong correlation between temperature (t) and productivity when the temperature is above or below the comfort zone (21-25^{o}C).

Based on the analysis the author develops a model to calculate productivity loss based on internal temperature, which we have adapted to calculate the productivity loss in our building. As we assume that our case study building is an office, we calculate productivity loss L, measured as a percentage and expressed by

$$L = 2 * t - 50, \quad 25^oC, < t < 32^0C$$

$$L = 0, 21^oC, < t < 25^oC \quad (2)$$

The loss of productivity or function depends on the building. As our case study is an office we calculate the loss of productivity and function based on salaries of employees.

The cost of an employee is based on the assumptions that (i) the annual salary of an employee is 350.000 DKK, (ii) the salary overhead is 2 and (iii) the number of working hours in a year is 2500. Then, the hourly cost per employee is

Hourly Cost per employee = 350.000*2/2500=350kr.

We assume that the cost of loss in productivity C_i can be calculated as following:

$$C_i = \sum_{i=25}^{32} N_e * C_{he} * N_{di} * L_i \quad (3)$$

where i is a temperature from 25…32°C
N_e- number of employees
C_{he} -hourly cost of employee in Dkr
N_{di}- number of hours between *i and i+1.*
L_i – productivity loss of employee for a threshold *i* in %

Similar, we can calculate the cost of loss of function when the building will be required to be shut down (G_2), and the cost of mortality of the occupants (G_3).

Other factors such as high humidity, which could influence the productivity of the occupants, can be included. However, in this example we restrict ourselves only to the temperature change.

Step 3 Determine the probability of the event/disturbance occurring

The resilience of a building to, for example heat waves, depends on a building's physical properties (location, orientation, building physics and ventilation type), the function of the building, and the climate in the particular location. To define the resilience for the particular building to a particular risk, in this case overheating, the resilience was investigated by applying a dynamic simulation for a model of the building first with a current weather file.

To investigate the building's performance for the future periods 2050 and 2100 we use a simple method to create a future weather file using annual change, based on (Cox R.A et al., 2014) where 5 future scenarios are created: one for 2050 and four for 2100. Then we simulate the building with these different future scenarios to determine the number of hours above the thresholds.

The predicted annual change for these 5 scenarios has been calculated by the Danish Metrological Institute (DMI) (Olsen M. et al., 2012) and based on IPCC SER scenarios (IPCC, 2011). The report uses a set of 13 regional models with different global circulation models to calculate the average annual and seasonal temperature change for IPCC scenarios A1B, A2 and B2 for the years from 2050 to 2100.

Table 2: Probability of increased temperature for current and future weather

	Current DRY	A1B 2050	A1B 2100	A2 2100	B2 2100	E2 2100
ΔT ^{o}C	0	1.32	2.9	3.2	2.5	2
Probability	100	90%	25%	25%	25%	25%

Step 4 Apply risk analysis to determine the expected cost associated with the current resilience

The expected costs can be calculated on the basis of the cost of building new, but recent extreme weather events are providing new statistical data about costs in cases of e.g. storms and flooding. We expect that in the future there will be a more developed basis for estimating expected cost.

Step 5 Determine cost of remedial solutions

The remedial solution is the solution that the property owner suggest based on current practices which focus on the technical standard of the building.

To incorporate sustainability, step 5 is expanded as following;

a) Determine capital and operating costs, as before
b) Determine direct/indirect ecological costs, e.g. carbon tax, etc
c) Determine intangible costs to say, reputation
d) Add (a)-(c) to determine total cost, then go to Step 6

Step 6 Apply cost benefit analysis to select (or not) a solution

The last step of the evaluation is to compare alternative solutions in a cost benefit analysis based on a set of indicator which are chosen based on the organisation policy, a building standard (BEAM, LEED etc.) or both.

Table 3: Comparison total cost for of different remedial solutions

Solution	Current conditions	Remedial solution A	Remedial solution B	Remedial solution C
Capital and operating costs				
Direct/indirect costs				
Intangible costs				
Total cost				

5 DISCUSSION AND CONCLUSION

The aim of the paper is to suggest a methodology that can measure the sustainable resilience of specific maintenance project, and to form a basis for evaluating if a specific solution (a maintenance project) is making the building more or less resilience to existing extremes and future extremes, i.e. how the proposed solution is more or less sustainable now and in the future.

We have suggested a 6 step approach to measure sustainable resilience to respond to a need for quantifying resilience and sustainability for maintenance planning. Our perspective is to link maintenance planning done by to FM organisation to meet the political agendas of resili-

ent, sustainable and well maintained cities in the way property management is executed. To some extent this can be done in a qualitative way, but in order to become more mainstream we have investigated how sustainable resilience can be expressed quantitatively, i.e. in monetary terms, to be able to be easily incorporated within the decision making process.
The paper reports work in progress and future studies have to be made to test the methodology and to co-develop it with property owners like Gentofte Property. However, the paper outlines the idea of our approach and supplements other studies (Jones 2012 and Jones et al 2013).

The 6 steps are explained but the first four steps are described more thoroughly than the last two. In the final version all 6 steps should be explained with same emphasis and tested. Currently there is a lack of data and agreed guidelines for quantifying sustainable resilience. However we expect that much more information will be available in the next few years due to current research and practice experiments.

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