Knowledge for Climate

Determining the Adaptive Capacity for flood risk mitigation: A temporal approach

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Determining the Adaptive Capacity for flood risk mitigation: A temporal approach

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Content

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Summary

Retrofitting urban areas to limit flood impacts can be an expensive and cumbersome endeavour. While it is difficult and costly to upgrade existing buildings and other assets, the construction of new assets provides opportunities for enhanced standards and pro-active retrofitting at possibly limited cost. This gradual upgrading strategy (i.e. opportunistic adaptation) depends on the age of the existing building stock, the spatial distribution, ownership and many exogenous factors (e.g. economic prospects). To assess this 'adaptive capacity' it vital to acquire knowledge about the end of lifecycle and replacement rate of assets. Although predictions on individual asset level are surrounded by large levels of uncertainty, a strategic insight of the replacement rate can be acquired on the level of larger areas or neighbourhoods. This research makes a first attempt at projecting the estimated end of lifecycle for buildings, infrastructure and utility lines within the Rotterdam area. Although the outcomes show a large degree of uncertainty, the main conclusions are that it might several decades until the majority of the building stock might be replaced or undergoes upgrading in major maintenance cycles. The opportunities for timely pro-active retrofitting are therefore limited.

1 Samenvatting

Het overstromingsbestendig maken van stedelijke gebieden kan een moeizame operatie zijn die gepaard gaat met hoge kosten. Het implementeren van nieuwe standaarden en maatregelen in nieuwe constructies is echter relatief eenvoudig. Deze graduele aanpassingen (i.e. opportunistische adaptatie) is afhankelijk van de leeftijd van de gebouwvoorraad, infrastructuur en nutsvoorzieningen alsmede van de ruimtelijke spreiding, eigenaar, en allerhande exogene factoren (e.g. het economische klimaat). Om deze 'adaptieve capaciteit' te bepalen is het van belang kennis te ontwikkelen over de levensduur/levensloop en het vervangingsgraad van de gebouwde omgeving. Hoewel het nauwelijks mogelijk is precieze uitspraken te doen over de verwachte levensduur van individuele objecten, is het wel mogelijk op buurt of regio niveau voorspellingen te maken. In dit project is een eerste poging gedaan om projecties te genereren van de levensduur van objecten in de regio Rotterdam. Hoewel de uitkomsten in zekere mate onzeker zijn, is de conclusie gerechtvaardigd dat het tientallen jaren zal duren voordat een substantieel deel van de gebouwde omgeving zal zijn vervangen. De mogelijkheid om het gebied middels opportunistische adaptatie te beschermen tegen overstromingen zijn daardoor beperkt.

2 Extended summary

Apart from upgrading the existing structural protection measures (e.g. dikes), urban adaptation to cope with (increasing) flood risk includes retrofitting of different types of assets within the built environment. This includes flood proofing of buildings, infrastructure and the utility lines. Although desirable, this upgrade is most of the times not performed in a single increment but in gradual steps over time. Even so, adapting the existing city to new standards often proves to be expensive and difficult especially in cases were no significant flooding has occurred in recent history. Yet during major renewal/maintenance cycles, retrofitting schemes can be mainstreamed into the planning of new constructions or major refurbishing. Depending on the end of lifecycle of the existing asset stock and the local flood characteristics, this so called 'opportunistic adaptation' can potentially facilitate flood mitigation measures without the need for large scale interventions. Furthermore, due to the gradual upgrading, new knowledge about climate change and subsequent river stages can be integrated over time.

In order to study the potential of such an approach, it is vital to gain insight into the urban dynamics of asset replacement (i.e. the expected lifecycles of groups of assets). Although still in its infancy, this study makes a first attempt at developing and applying a methodology that estimates the end of lifecycle of buildings, infrastructure, public space and utility lines in the Rotterdam unembanked area. Based on the construction year and expected lifespan, the individual asset's end of lifecycle is determined. Except when performing critical functions, it is unfeasible that individual assets are replaced. Therefore a hierarchic system of inheritance has been developed where dominating assets pass their end of lifecycle on to dependent assets. For instance, only when a street is upgraded the subsurface utility system (i.e. pipe network) will be replaced. Furthermore, within asset classes, the replacement of groups often prevails over the replacement of individual assets; if possible, complete housing blocks are replaced instead of individual units. The outcomes of this study are based on this approach. Furthermore, since the lifespan of assets (especially buildings) is dependent on a large set of endogenous and exogenous factors, a stochastic approximation has been developed in which the uncertainties stemming from ownership and other factors is expressed. This provides the outcomes with ranges instead of fixed future moments in time in which (sets of) assets reach the end of their lifecycle.

The final aim is to gain some insight in the potential adaptation rate (i.e. the adaptive capacity) when flood adaptation is exclusively performed through proactive retrofitting of new constructions. The outcomes show that due to the relatively long lifespan of Dutch buildings, the possibilities for gradual upgrading are limited.

3 Introduction

The previous flood impact assessment in this report focused on the current and future hazard, exposure and sensitivity of the assets located in the study area. Nevertheless, the sensitivity of the assets to flooding was considered to be static; the potential effects of future changes in the urban environment were disregarded. Yet, in the common understanding of flood risk assessment, future changes in sensitivity are important indicators that might either increase or decrease potential impacts. Often these changes are combined in the concept of 'adaptive capacity' (REF), which encompasses all potential future changes (e.g. behavioural, economic, technical, spatial, etc.) that influence future hazard, exposure and/or sensitivity to flooding. Note that most authors differentiate between the 'adaptive capacity' and the 'coping' and/or 'recovery capacity'. While the former focuses on the ability to cope with long term changes (e.g. climate change) the latter define the ability to endure and recover from an actual flood event. As a consequence, an important factor to determining the adaptive capacity is the rate a receptor (e.g. a building or neighbourhood) can keep up with trend changes in flood risk. While section xx of this report focuses on the available range of adaptation measures in the study area, this section focuses exclusively on the temporal dimension defining the potential adaptation *rate* of individual assets, areas and neighbourhoods. Taking the urban renewal cycle as an opportunity for the implementation of pro-active retrofitting measures, adaptation measures can be distributed over a longer periods. Apart from the fact that this might be more cost-efficient, it also provides possibilities of for better integration of flood risk management policies and subsequent measures into actual urban development and redevelopment; instead of being a passive receptor, the city becomes an active component in flood impact mitigation. Another advantage of this integration is that the uncertainties associated to the rate of climate changes and the subsequent sea level rise and river levels can be dealt with in a more responsive and flexible manner. Instead of agreeing on a climate change scenario and implementing measures now, continuous incremental improvement is provided by small scale re-adjustments during the design and standards whenever assets undergo major reconstruction or are replaced. Obviously, this strategy only works for areas that are 'up to standard'; for areas that currently fall below standards there exists an immediate urgency for minor or major upgrading.

Using the urban renewal cycle for mainstreaming flood proofing measures is a relatively new concept. Theory and methodologies to access benefits are in their infancy. Although advantages have been identified on a conceptual level (e.g. Zevenbergen et al, 2008; Veerbeek et al, 2010), operational methods are limited (Gersonius, 2012) and need further refinement and testing. Nevertheless, a first attempt has been made to operationalize a model that estimates the renewal cycles of different asset classes (e.g. utility networks, roads, buildings). The following chapters will introduce the methodology and application of a lifespan-assessment model that attempts to estimating future possibilities for mainstreaming adaptation measures in urban redevelopment. Although a significant level of uncertainty is clouding some of the outcomes, the results provide a strategic outlook on future flood adaptation for the study area as well as for the complete Rotterdam unembanked area.

4 Methodology

4.1 Introduction

Although the discipline of asset management has a considerable history in which important scientific accomplishments have been reached, models attempting to estimate the end of lifespan of complete areas consisting of multiple and different types of assets (e.g. roads and buildings) are in their infancy. Typically asset management focuses on single system assets by an economic/technical perspective. Often the lifespan of these systems is well defined (e.g. drainage networks). Note that this doesn't necessarily mean in practice that replacement or upgrading occurs at the end of this period. In many cities in Europe and North-America the aging urban drainage network exists well beyond its estimated lifespan. This is due to the significant costs associated to renewing the system resulting in a 'monitor-and-repair' policy that keeps the system operating well beyond its estimated end of lifecycle (EOLC). This example expands to other areas, where depending on the conditions (e.g. market conditions, changes in the depreciation schemes) the lifespan of assets is stretched well beyond their initial expectancy. This makes a reliable prediction about the lifespan of individual assets uncertain and the applicability in actual practice problematic. Yet, the estimation of the EOLC should therefore be regarded as guideline. Furthermore, the deviations from the expected EOLC caused by exogenous factors are somewhat dampened when large quantities of assets are taken into account, making assessments predominantly applicable for the strategic planning of larger areas.

Before elaborating on the applied methodology, it is important to address the distinction between technical and economic lifespan. While the technical lifespan focuses on the functional period of operation, the economic lifespan covers the depreciation period of an assets investment value. Note that these two periods can differ significantly, e.g. the technical lifespan of a dwelling is often beyond 100 years, while the economic lifespan mostly spans a period of 30 years. Furthermore, maintenance cycles and incremental upgrading can further extend the technical lifespan and introduce new investments and their associated depreciation periods that effectively increase the economic lifespan as well (e.g. Templemans Plat, 1990). For this study we focus mainly on the technical lifespan of assets since obtaining data about the different depreciation models applied by the respective owners proved to be too difficult to acquire. Furthermore, many private homeowners do not follow a rational depreciation scheme since they regard their home both as investment and dwelling.

4.2 Estimating the EOLC

To estimate the EOLC a differentiation has been made between different sets of assets. To some extent this classification was based on the available data. The assets classes consist of:

- *Buildings*. All buildings including housing, offices, retail, public services, cultural facilities and industry;
- *Infrastructure*. All roads, parking space, railway, metro and tramlines;
- *Public Space*. All other areas including sidewalks, squares and green zones;
- *Utilities*. All underground structures including gas lines, electricity and telecommunication.

The first challenge in the data preparation stage was to determine the construction year of all individual assets. While the construction year of individual buildings is stored within the municipal records, for all other assets the construction year was unavailable. To overcome this problem an 'inheritance'-method has been developed, where the assumption is made that the construction year of assets (e.g. roads) is equal to the average construction year of clusters of buildings. Depending on the variability in the building's construction years within an area, these clusters essentially represent blocks or neighbourhoods for which it seems safe to assume that they have been built as complete units including access roads, public space and utility network. To acquire the clusters, a neural gas (Martinetz et al, 1991) inspired clustering algorithm has been developed that identifies sets of buildings with a bounded range of identical construction periods. Anomalies (i.e. redeveloped individual buildings originating from a different period) were filtered out using a 95% confidence interval in the individual construction year ranges within the clusters. To assign the average cluster construction year to the adjacent assets, a Voronoi diagram was constructed that was intersected with the assets' centroids. The outcomes are presented in figure 1, in which can be observed that relatively large clusters exist of areas built during the same period. This especially holds for the central part of the region (the Rotterdam-Enterpot area). Differentiation can be clearly perceived on the Noordereiland where the central part hosts the oldest structures while the head and tail of the island consist of more recently built areas. Furthermore, the clusters on the head and tail of the Noordereiland often consist of single or small amounts of (housing) blocks.

The lifespan of individual asset classes has been estimated by a combination of expert knowledge and a literature review (Hoogers et al, 2004; Van Dam et al, 2006) and are presented in appendix 1. A major obstacle in this process was that there seems no consensus among experts nor is there reliable data available about this topic. This is partly due to the fact that especially experts from the real estate market or housing corporations cover limited portfolios of buildings. Market conditions and other factors influencing the lifespan of buildings are therefore perceived as the dominating forces determining maintenance, refurbishment or replacement. Additionally, economic and technical depreciation and lifespans are often interchanged which muddles the estimates. Reliable time-series data is unavailable for buildings since the relatively long lifespan of buildings, often spanning more than 100 years, prevents the creation of long-term records. Many building locations within the study area are still in their first generation. For infrastructure the maintenance and renovation/replacement strategies are often mixed. While major access roads are incrementally renewed within relatively fixed periods, the maintenance scheme for local roads is mostly based on monitoring, i.e. repair work is based on reports or notifications from residents/users. This causes a significant level of variability within the lifespan of different road classes. Many elements in public space (e.g. green zones) are dealt with in a fairly flexible manner; here the lifespan is often determined by usability and functional requirements.

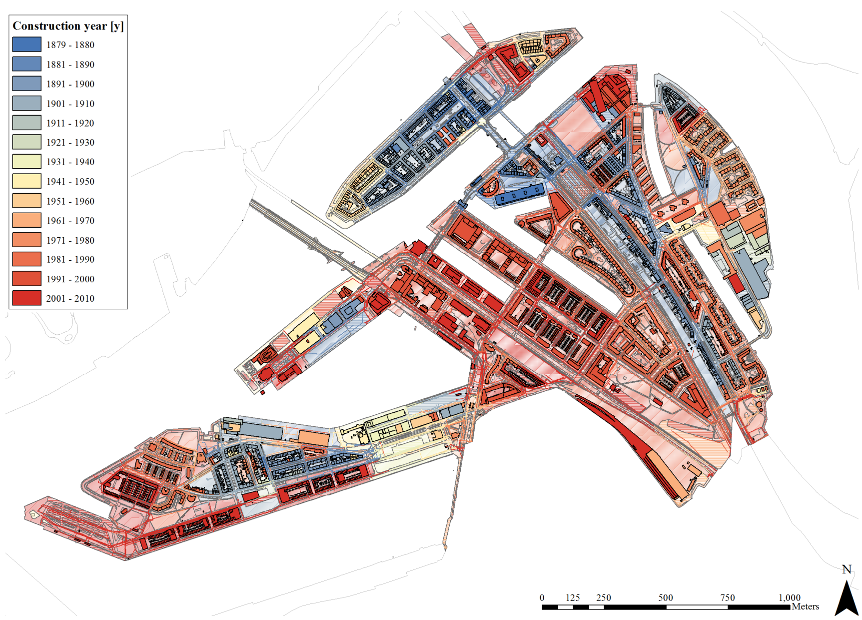


Figure 1: Estimated construction year of assets within the study including inherited construction years for infrastructure, public space and utilities.

The estimated lifespan of individual asset classes differs significantly. While local roads are estimated to have a lifespan of about 30 years, upscale market buildings dating from the early 1900s might have lifespans up to 150 years or longer. Consequently, by now, many roads might already have been renewed several times while some of the buildings are still operating within as a first generation. To estimate the first future estimated EOLC, the assets estimated lifespan has been multiplied from its construction year till the earliest point in the future; e.g. a road constructed in 1950 with an estimated lifespan of 30 years, is expected to reach its EOL in 2070 (3 times its lifespan). This is illustrated in figure 2, where the earliest EOLC for a given road is estimated to around 2024.

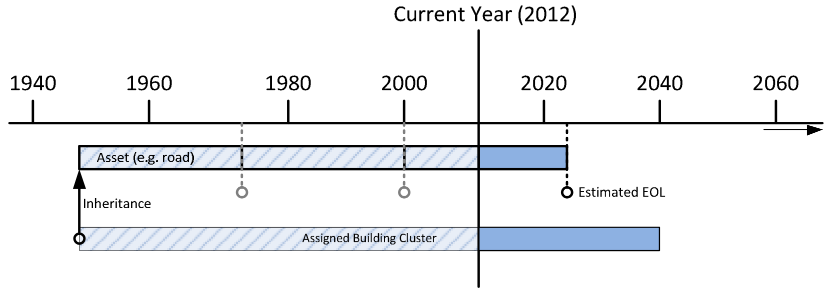


Figure 2: Overview of basic methodology to estimate future EOL

5 Observations

5.1 General observations

This previously described method is applied for all identified assets within the case study area. The aggregate results are presented in figure 3, which show the ratio of assets reaching the EOLC until the year 2100. The outcomes are presented for the study area as well as for the total Rotterdam metropolitan area. This is done to examine if the results for the case study area can be generalized.

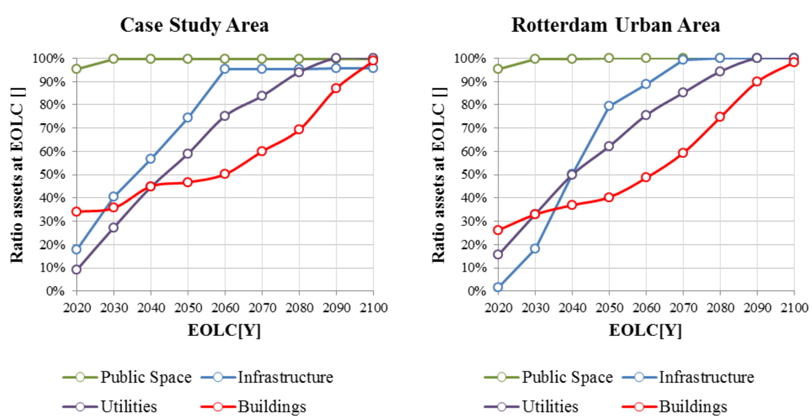
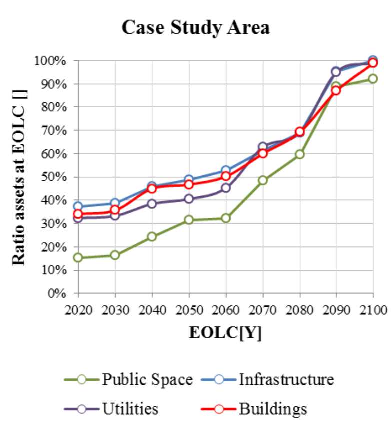


Figure 3: Estimated EOLC for the case study area (left) and the Rotterdam urban area (right)

The first observation that can be made from figure x is that the outcomes for the case study area are relatively similar to the Rotterdam metropolitan area. What can be furthermore perceived is that the estimated ratio of buildings reaching their EOLC evolves sluggish compared to all other assets. This especially holds for public space, where already in 2030 all assets reached their estimated EOLC. This is a direct consequence of the relatively short lifespans that are assigned to many of the assets in public space. Yet, the figures also show that currently, about 30% of all buildings have already reached their EOLC, and are up for major refurbishing or redevelopment. This is to some extent confirmed by observations on site; many buildings in especially Feijenoord are out dated and in some cases are unoccupied. Apart from the building stock, the ratio the utility network reaching their EOLC over the coming decades, also increases relatively gradually. Furthermore, as for infrastructure, the rates increase in an almost linear fashion, indicating an almost uniform distribution of the estimated EOLCs over the analysed interval.

These outcomes would suggest that there are ample opportunities for retrofitting assets by replacement or upgrading at the estimated EOLC. The question remains to if these identified opportunities can be regarded independently; e.g. replacement of segments in the utility network rarely would proceed without also upgrading the overlaying roads and public space. Therefore, independent pro-active retrofitting of individual assets might prove to be too expensive to be considered as a feasible strategy; if retrofitting is considered, they should probably integrated the redevelopment plans for larger areas. Thus the question remains what physical elements reaching the EOLC can be regarded as the drivers for pro-active retrofitting schemes. On the one hand these would consist of critical components (e.g. a segment in a main access road) that are vital for on local or even regional scale. On the other hand, there seems to exist a hierarchy within the different asset classes, where building development is often the main driver for redevelopment of a complete area (i.e. block, street or neighbourhood). To examine the effects of integrated pro-active retrofitting, where the estimate EOLCs of assets are synchronized with the average EOLC of the surrounding buildings, an alternative model has been developed in which the EOLCs of utilities, public space and infrastructure are inherited from the average EOLC of building clusters. This methodology could be seen as an extension of the 'shearing layers'-concept (Duffy, 1990) in which the lifecycle of building components are compared and related.

The outcomes of this approach are presented in figure 4, where the EOLCs of asset sub-classes (infrastructure, public space and utility network) is inherited from a super class (buildings). The assignment of the inherited EOLC is performed in a similar fashion as for the assignment of the construction year.



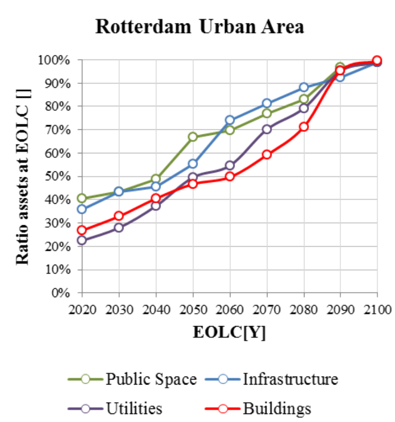


Figure 4: Estimated EOLC for the case study area (left) and the Rotterdam urban area (right) using inheritance.

The outcomes show a much more coherent relation between the different asset classes. This seems intuitive since the EOLC of individual assets follow those of adjacent building clusters. Note that this would only be the case for an even spatial distribution of assets. Which with the exception of public space, this is confirmed for both the case study area and the Rotterdam metropolitan area. For public space, until 2090 the ratio of assets reaching the EOLC in the case study area is significantly lower than that for other assets. In the Rotterdam metropolitan area, this issue is reversed; both the ratios for infrastructure and public space are significantly higher than for the building clusters and to a lesser extend for the utility network.

To further investigate these observations a map has been produced that shows the average estimated EOLC for building clusters and the inherited EOLC for all other assets (see figure 5). Note that the assets shown in grey are regarded as static elements. In the case of buildings these include protected cultural heritage. In the case of in infrastructure these contain bridges, tunnels and railway tracks.

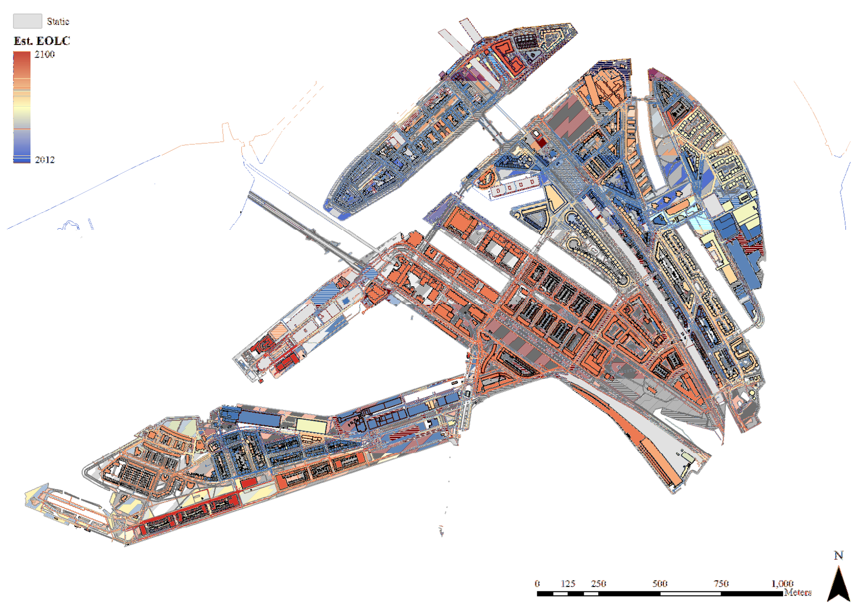


Figure 5: Estimated average EOLC of building clusters and inherited EOLC of surrounding assets

What can be clearly perceived from figure 5, is the dominance of the individual building clusters over the surrounding areas. This means that that the clusters are of considerable size, often consisting of multiple building blocks or even complete neighbourhoods. For the individual neighbourhoods, the following can be concluded:

- *Afrikaanderbuurt*. Due to recent redevelopment, the estimated EOLC is beyond 2100.

- *Feijenoord*. Main clusters can be identified along the Oranjeboomstraat, the eastern part of the Feijenoord Eiland-Oost and around the Persoonhaven. Especially the area along the Oranjeboomstraat is reaching its EOLC. Almost all other areas will reach their EOLC within the coming 50 years.
- *Katendrecht*. Katendrecht is clearly divided into areas that have already reached their EOLC and recently built areas that will reach their EOLC only at the end of this century;
- *Kop van Zuid*. This area is almost complete reconstructed in the past decade. The EOLC is therefore estimated only at the end of this century;
- *Kop van Zuid*-Entrepot. Same as Kop van Zuid;
- *Noordereiland*. The majority of the Noordereiland reached the EOLC. Note that some of the buildings in this area are considered as static elements since they are considered cultural heritage and are therefore protected against major refurbishing or demolition. Next to the Erasmusbridge a new block has been developed that can be considered as an anomaly on the island; the estimate EOLC is beyond the year 2100;

From all neighbourhoods within the case study, the majority of assets within Feijenoord, Noordereiland and (parts of) Katendrecht have already reached their estimated EOLC or will do so in the coming decades. Most other areas have been redeveloped recently which means that the next redevelopment cycle will be reached possibly only around 2100 or beyond. This would suggest that timely pro-active retrofitting opportunities for the area are limited.

5.2 Extending the method

From a methodological perspective, these outcomes would suggest that even for a relatively small area (i.e. an individual neighbourhood or smaller), the estimated EOLC s can be clustered into larger zones which potentially opens op integrated future pro-active retrofitting opportunities beyond the individual asset level. Yet, this conclusion might be premature. Although a rational appraisal of depreciation and associated lifespans provides insight in future opportunities, the estimated EOLCs are in practice influenced by a large level of uncertainty. To gain some insight in the influence of this uncertainty on the outcomes a sensitivity analysis has been performed in which the lifespans for the different asset classes are not fixed to single periods but are probabilistically assigned with values drawn from predetermined ranges. Since the estimated EOLC of building blocks are assumed to be the main drivers for pro-active retrofitting of areas and the majority of buildings consist of housing, the sensitivity analysis is focused on the different factors that could shorten or extend the lifecycle of the housing stock. To do this, the housing stock's data set for the area was extended with a set of variables that include:

- *Ownership*. Privately owned residential units are assigned with a larger range in lifespan than those owned by institutional owners (e.g. housing corporations) that manage a relatively vast housing stock. Additional ranges have been determined for private companies and individuals owning a medium sized housing stock (i.e. between 2-10 units), municipalities, etc.
- *Valuation.* Upscale market residential unites tend to have longer life-spans than for instance social housing units. This especially holds for older houses that are often incrementally renovated/upgraded effectively extending their lifespan significantly.

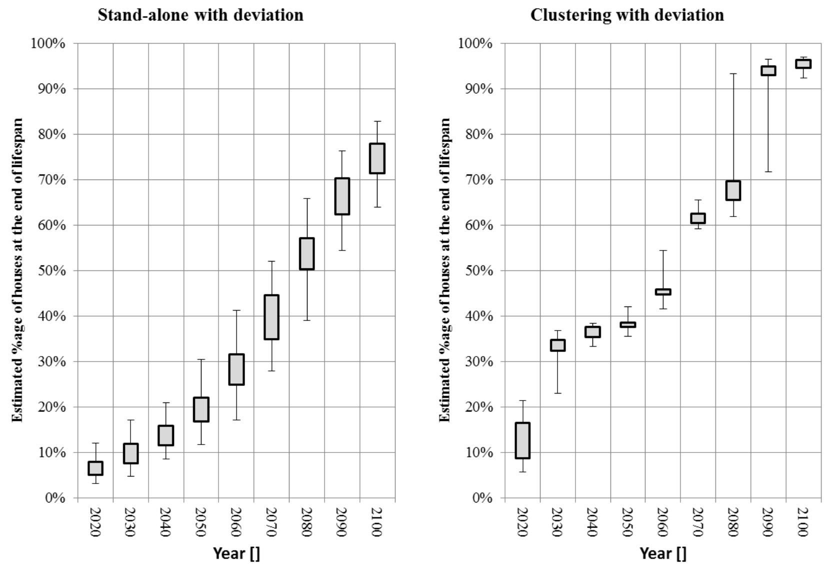
These factors are neither exhaustive nor are they based on a thorough assessment of their relative importance. Extensive socio-economic research needs to be performed within the real estate market to further develop these factors. The ranges, from which the lifecycle extensions are estimated, reflect the uncertainties for the different ownership classes. For instance, for units owned by housing corporations, the lifespan extension can vary between 0 and 15 years, while for privately owned houses this range increases to 50 years. The rest of the applied ranges from which the EOLC are drawn are presented in appendix 1. Note that the probabilistic assignment has been performed by using a normal distribution using the positive end of the distribution (i.e. lifespans have not been shortened).

The outcomes of this analysis are presented as a boxplot in figure 6. These come in 2 versions:

- *Stand-alone with deviation*. Here the outcomes estimated EOLCs have been assigned to individual houses after which the ratios of assets reaching the end of the EOLC until 2100 have been determined;
- *Clustering with deviation*. Here the estimated EOLCs have are based on the most frequent ownership type within a cluster after which the EOLC is probabilistically assigned.

The mean, quartiles, minimum and maximum values are based on the outcomes produced in 50 runs.

Figure 6: Estimated ratio of buildings reaching EOLC using probabilistic assignment of lifespans, based on individual buildings (left) and clustering (right)



The most important observations are that across the different years, the variability within the quartiles as well as within the min-max range remains limited when the EOLCs are assigned to individual assets (figure 6, left). In the case of clustering (figures 6, right) the variability within the quartiles becomes almost negligible (often within 4%) but the total range increases shows large variability. Outliers can be identified for 2030, 2060, 2080 and 2090 suggesting large levels of uncertainty about the ratio of houses reaching the EOLC. This suggests that gradual adaptation by mainstreaming pro-active retrofitting during urban renewal is only possible on a house-to-house basis. Redevelopment of large clusters could imply postponing the retrofitting actions or rushing the actions due to early retirement of housing units. Note that these estimations differ when focusing on neighbourhood level. These outcomes are shown in Appendix 1.

6 Interpretation

One of the most important observations of this study is that mainstreaming adaptation with the urban renewal cycles on street, block or neighbourhood level (i.e. cluster level) significantly delays the upgrading of flood protection standards. The ratio of estimated EOLCs for infrastructure, public space and utilities when treated as stand-alone assets, quickly increases (see figure 3). Apart from buildings, an estimated 75% of all assets are reaching their EOLC before 2060. When the lifespan of assets is extended until major reconstruction of buildings in the area, this level is only reached in 2090 (see figure 4). This period could potentially be longer due to the uncertainties in relation the depreciation periods of buildings (see figure 6).

7 Conclusions

Although the mainstreaming of adaptation and subsequent pro-active retrofitting with urban renewal might lead to an embedding of an adaptation strategy within urban development, the question remains if the study area, or more generally, the Rotterdam metropolitan area can afford to wait. This is to some extent depended on then identified flood risk in the areas; areas with only limited flood risk might not need urgent action to upgrade protection standards. Furthermore, increased knowledge about the trend changes in sea level rise and river levels might favour a strategy that is not only flexible in its protection level, but also in time (e.g. Gersonius, 2012). Probably, it is safe to conclude that a mixed-strategy is needed in which the protection standard for the most vulnerable areas is upgraded to a sufficient level (either by limiting hazard, exposure or sensitivity). Future adaptation can then proceed incrementally and be synchronized with the identified renewal cycles.

The estimation of the EOLC of various asset classes in the project area provides strategic information that could provide a guideline for opportunistic adaptation (i.e. adaptation integrated in urban renewal). Especially on a larger scale level, it could provide opportunities for long term regional and national adaptation strategies.

8 Recommendations

The estimation of urban renewal cycles is not a trivial task. Modelling of such processes is data intensive and ultimately surrounded by substantial level of uncertainty. Much research and monitoring is needed on the various depreciation schemes applied by various groups of assets owners. Furthermore, extensive records need to be developed that indicate the construction years, maintenance cycles and ultimately the refurbishing/replacement of various asset types. Only then can models be validated which is a key ingredient for application and further refinement.

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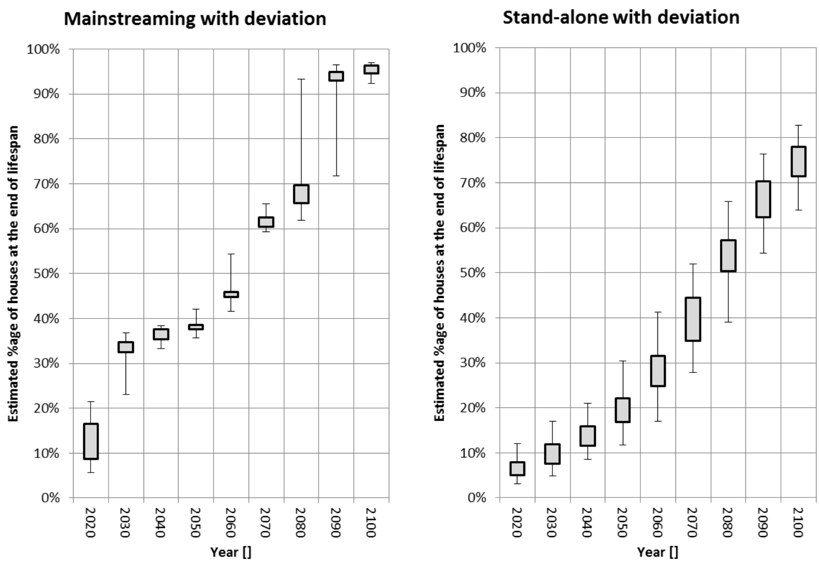
10 Appendix

The presented graphs in the appendix show the expected EOLC for housing using the probablistic assignement method described in 5.2.

Project Area



Rotterdam Urban Area

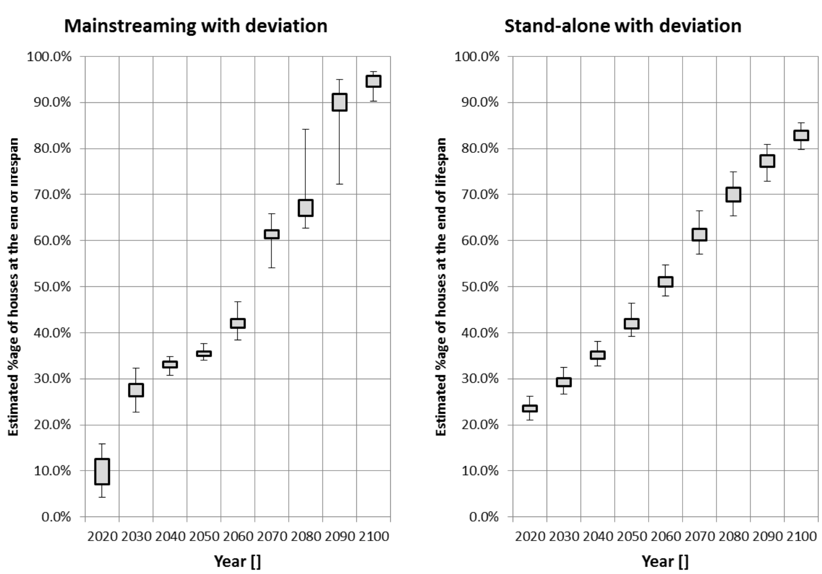
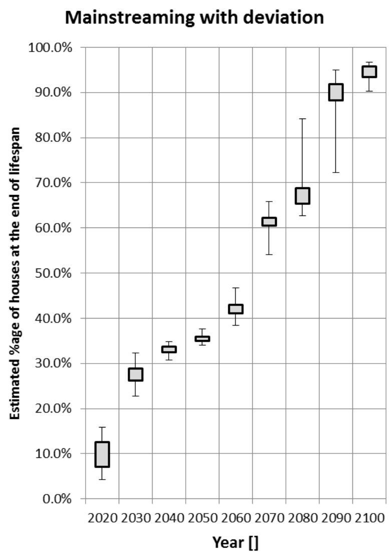
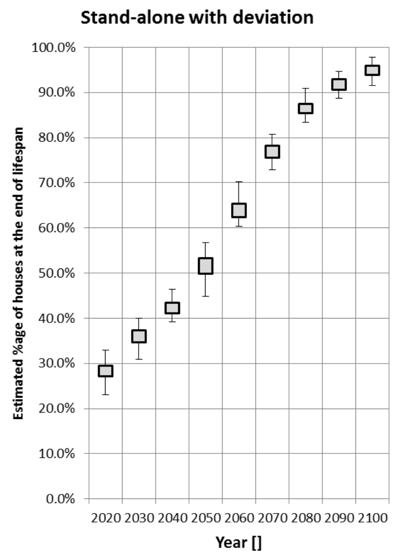


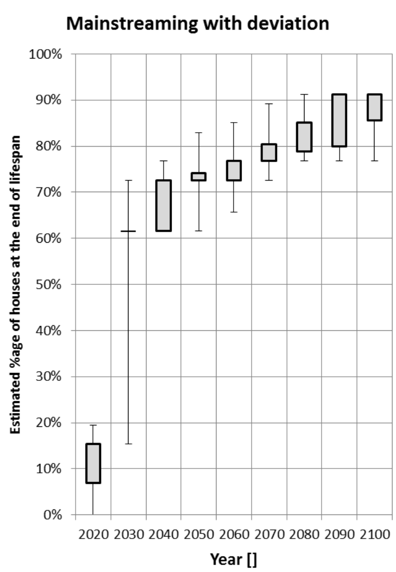
Figure 1: Estimated ratio of buildings reaching EOLC using probabilistic assignment of lifespans, based on clustering (left) and individual buildings (right).

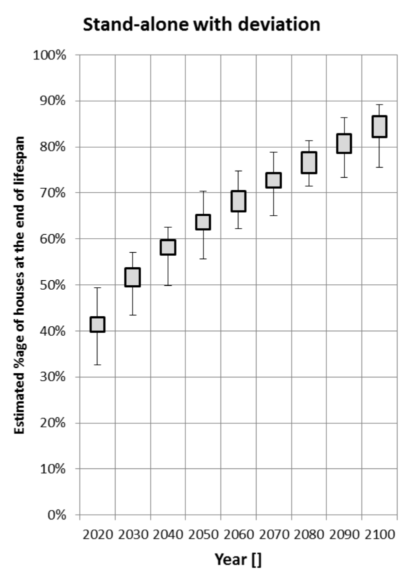
Feijenoord



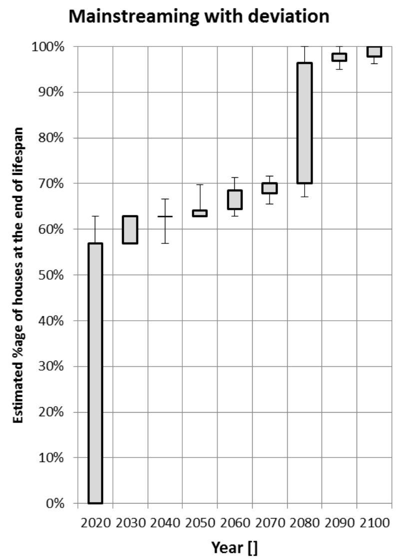


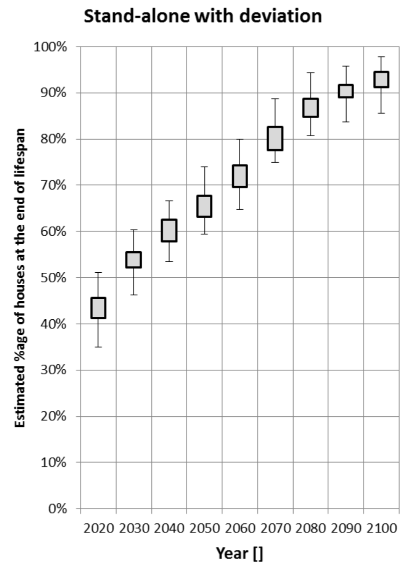
Noordereiland



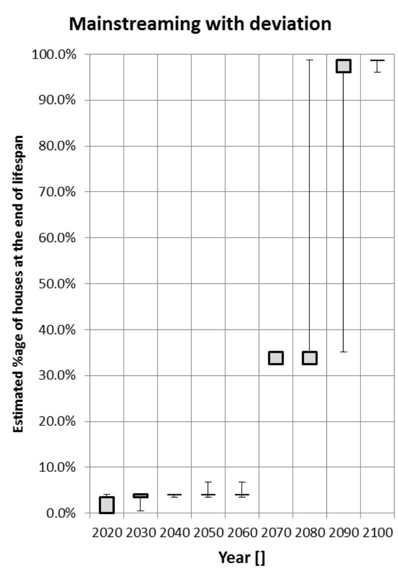


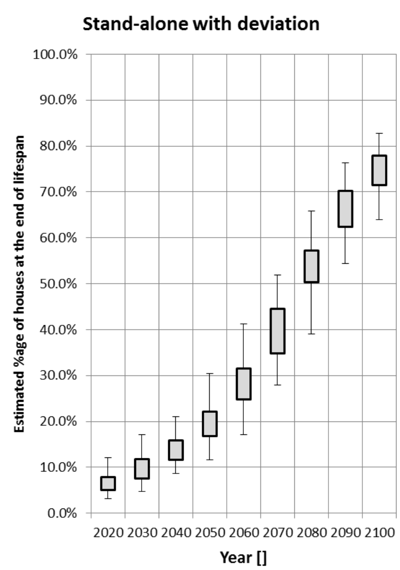
Katendrecht





Kop van Zuid-Entrepot





To develop the scientific and applied knowledge required for Climate-proofing the Netherlands and to create a sustainable Knowledge infrastructure for managing climate change

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