Approach to balance maintenance schedules for built assets according to a 40 year maintenance life cycle

Dipl.-Ing. M. Eng. Jens-Helge Bossmann
Karlsruhe Institute of Technology (KIT)
jens.bossmann@kit.edu
+49 721 608-46008

Dr.-Ing. Carolin Bahr
Prof. Dr.-Ing. Kunibert Lennerts
Karlsruhe Institute of Technology (KIT)
+49 721 608-48225

ABSTRACT

Adequate building maintenance is one of the most important influences on sustainability and durability of built assets. Therefore the Karlsruhe Institute of Technology (KIT) developed the so-called "PABI" Budgeting Tool (Practical, Adaptive Budgeting of Maintenance Measures), to help maintenance experts to evaluate their future maintenance budgets. Previous calculation results with the PABI Budgeting Tool reveal that the maintenance expenditures may differ significantly from one year to another according to the composition of the asset particularly in terms of its age structure and the detected maintenance lifecycle of 40 years. However, facility managers prefer a rather balanced yearly maintenance schedule and budget due to financial and personnel company restrictions. Hence the present research in a first approach shows how to balance large maintenance schedules in order to achieve an almost constant level of annual maintenance costs. To do so four reallocation steps were developed and applied to an exemplary asset of 824 church buildings by the Protestant Church in Baden. At this the required reallocating steps were based upon different operation standards defined by the church representatives and maintenance experts as well as building data, in particular the current building condition. As a result it has been possible to balance the schedule of the entire asset of 824 buildings within a 40-year maintenance life cycle.

Keywords

Building maintenance, maintenance schedule, maintenance budgeting.

1 INTRODUCTION

Adequate building maintenance effectively helps to slow down the aging of building elements and materials. Building maintenance therefore is one of the most important influences on sustainability and durability of built assets. To improve the quality of maintenance, the Karlsruhe Institute of Technology (KIT) developed the so-called "PABI" Budgeting Tool (Practical, Adaptive Budgeting of Maintenance Measures). Based on numerous statistical analyses covering empirical maintenance costs of office-, school-, residential and church buildings the PABI-Tool was consistently advanced and adjusted. Today it enables the user for to calculate the essential maintenance costs for a large asset in a transparent and simple way. Calculations with PABI reveal that the maintenance expenditures may differ significantly from one year to another according to the composition of the asset particularly in terms of its age structure and the detected maintenance lifecycle of 40 years. However, facility managers favor a rather constant and balanced yearly maintenance schedule and budget due to financial and personnel company restrictions. Hence the present research aims at balancing the maintenance schedule of large assets by reallocation based upon the building condition and generic building data with the goal to avoid large deviations in the future maintenance budgeting.

2 METHODOLOGY

The study is based on quantitative research methods, especially the analysis of empirical maintenance data of an asset of 824 sacral buildings of the Protestant Church in Baden. The corresponding data was transformed into a data base, covering the year of erection, the dates of the last extraordinary maintenance measures and the description of the current building condition. The reallocation of the asset was carried out in 4 steps based on different building specifications and the operation standards that were newly defined with the help of expert interviews (e.g. buildings with detected maintenance backlog have high priority etc.).

3 DEFINITIONS

All maintenance related terms used in the study are based on definitions of the German Standard DIN 31051 2003-06 - “Fundamentals of maintenance”, covering “service”, “inspection”, “repair and overhaul” and “improvement” measures. The presented results concentrate exclusively on measures of “improvement” (one-off measures with project character) including measures on the building shell and the building interior. The corresponding maintenance costs needed are called “extraordinary” maintenance expenditures according to the PABI Calculation Tool.

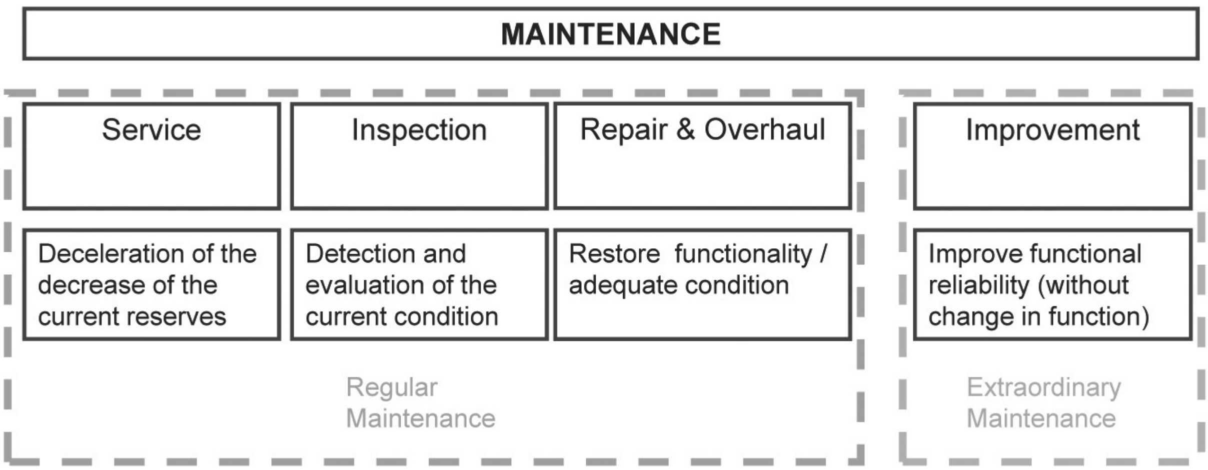

Figure 1: Definition of maintenance according to DIN 31051:

4 RESULTS

4.1 Asset Structure

The asset includes 824 sacral buildings built throughout various building periods. The oldest church dates from the year 875, while the youngest building was finished in 2005. Hence, there have been numerous building activities in terms of new church constructions for the past 1130 years. Nevertheless the number of churches built per year varies significantly. There were numerous years in the history of the asset, when no new buildings were constructed whereas in the year 1955, 18 new sacral buildings were finished.

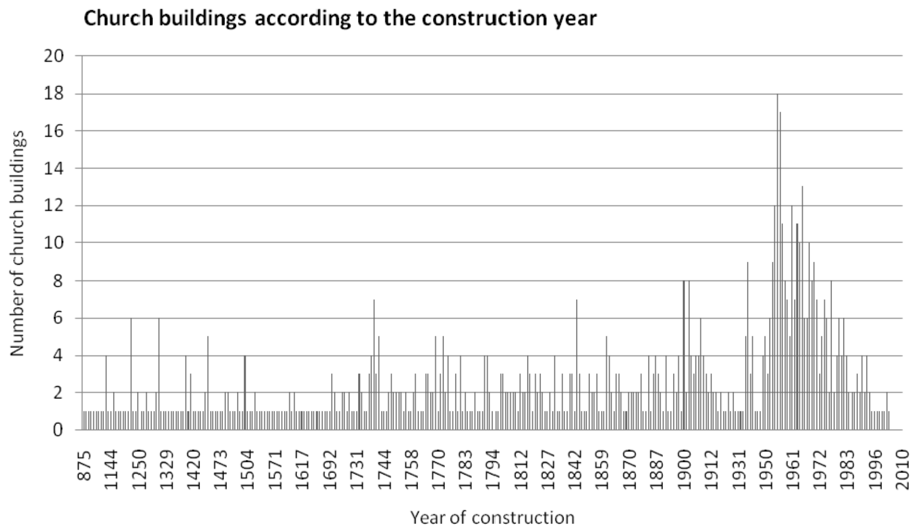

Figure 2: Distribution of new church buildings according to construction year

The diagram shows that the intensity of the building activities over the centuries has been constantly shifting. Periods of higher building activities were followed by periods of lower activities and vice versa. Nevertheless there have been periods of explicit higher building activity for example the period after the Second World War (1950 – 1975). However, this phase of highest activity contrasts with phases of very low activity, in particular the years during inflation (end of the 1920s), the Second World War (1938 – 1945), and more recently the period since the beginning of the 1990s.

According to figure 3 more than one third (35%) of the church asset was built in the period from 1950 to 2000. If you add the buildings, built in the period from 1900 to 1949 (12%), you can see that nearly half of all church buildings (47%) of the Protestant Church in Baden were built in the 20th century. The remaining 53% of the asset are subdivided as follows: 19% of the church buildings were constructed in the 19th century, 17% in the 18th century and another 17% in the period from 1699 going back to the year 875.

The variations are due to several influencing factors: For example social (demographic development), economic (financial crisis, inflation etc.) and political (wars) reasons.

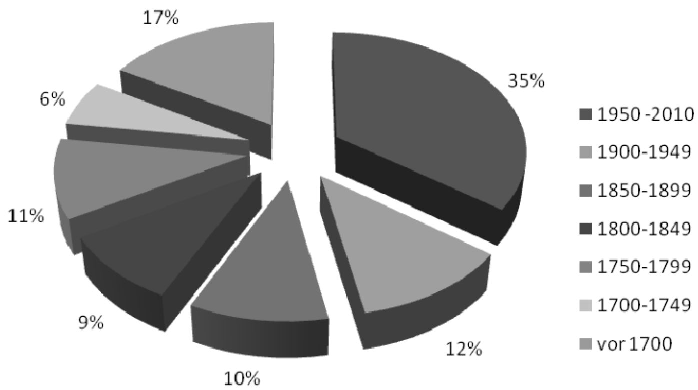

Figure 3: Percentage distribution of church buildings according to construction year

4.2 Definition of the “40-Year Maintenance Life Cycle”

Previous research results have proven that extraordinary maintenance measures normally take place in the period in-between the 30th and 40th year after construction (Bahr, C. 2008). This fact also applies to the majority of all postwar church buildings.

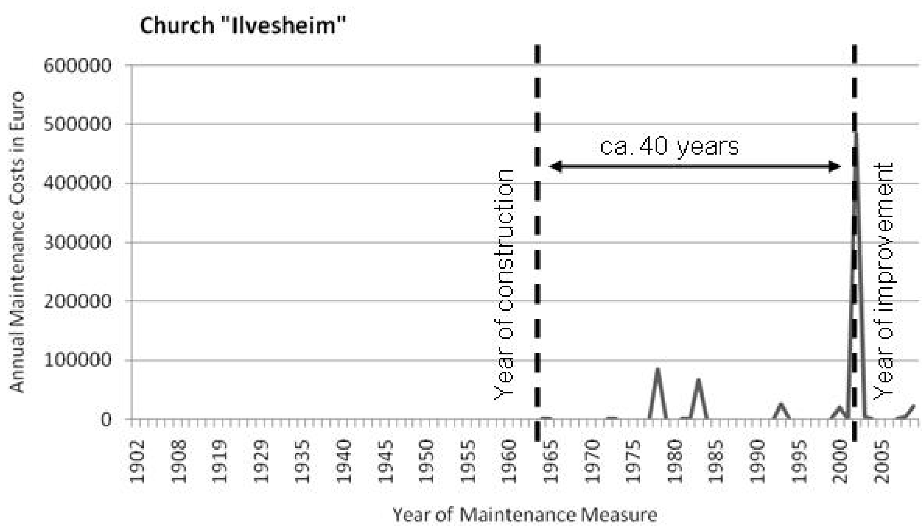

Figure 4: Progression of extraordinary costs using the example of the church “Ilvesheim”

In case of those sacral buildings constructed before 1945, the corresponding analysis of prewar church buildings lead to the assumption that the time period of 30 to 40 years is also suitable to describe the presumable period in-between two extraordinary maintenance peaks including all age groups of sacral buildings. The majority of the analyzed prewar buildings actually show a ca. 40 year cycle.

The maintenance life cycle for the reallocation of the church asset was therefore defined to be 40 years.

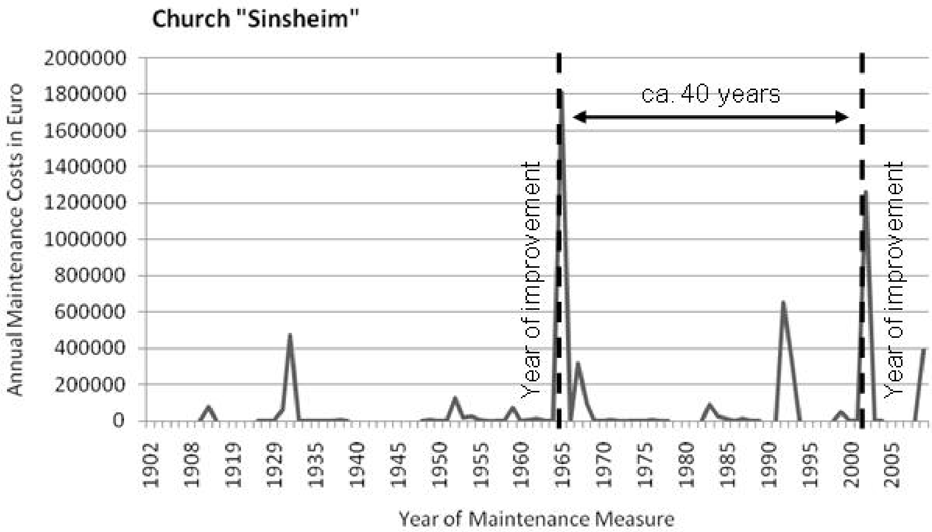

Figure 5: Progression of extraordinary costs using the example of the church "Sinsheim"

4.3 Approach to balance the maintenance schedule of the church asset

The main goal of the research was to balance the maintenance schedule of the existing church asset to the greatest possible extent to secure a rather constant future level of required maintenance costs. Cost peaks like they occurred in the past should be effectively avoided.

The maintenance life cycle was determined on a period of 40 years, according to the results of previous research projects [Boss08], (Bahr08] as shown in chapter 4.2. To rearrange the total of 824 church buildings within the 40-year life cycle several reallocations became necessary.

4.3.1 First Reallocation based on the "Latest Extraordinary Maintenance Measure"

The first reallocation of the asset was done on basis of the last extraordinary maintenance measure that was carried out on the interior or shell of each sacral building. To do so, the year of the building construction was replaced by a fictitious year of construction namely the year when the last extraordinary maintenance measure was accomplished. The procedure is based on the presumption that a completely renovated building by means of an extraordinary improvement action may be classified as a new.

Figure 6 visualizes the generated graph of all extraordinary maintenance measures carried out since 1949 regarding the building shell and the building interior. The total number of all improvement measures according to DIN 31051 is 1450.

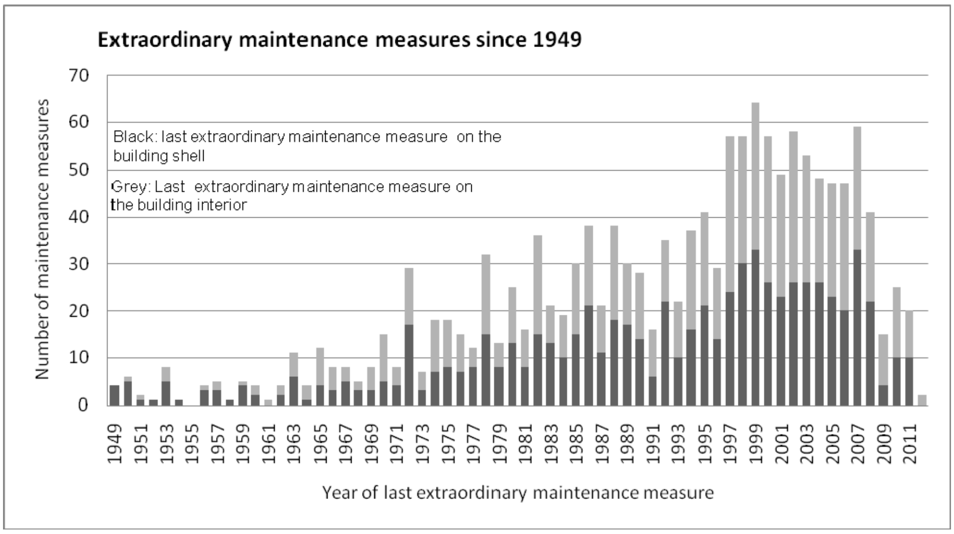

Figure 6: Distribution of the church asset according to the latest extraordinary maintenance measures

There are 719 maintenance measures documented on the building shell and 731 measures on the building interior. Further differentiations show, that 91% of all church buildings have had at least one extraordinary maintenance measure on the building shell or interior in the past 100 years. There were no improvements recorded for only 9% of the asset. These are mainly new churches which have not yet reached the phase of increased maintenance needs.

In 1973 only 7 improving maintenance actions have been recorded, while for the peak year in 1999 even 64 maintenance actions have been successfully accomplished. The difference shows that the maintenance activities have not been operated on a constant level, but have been subject to strong deviations. In the years from 1971 to 1996 for example the average activity is about 24 maintenance measures a year. Contrary to this the average jumped up to 54 maintenance measures per year for the period from 1997 to 2007.

The strong increase in terms of the accomplished maintenance actions can easily be explained looking at figure 2. Corresponding to the high number of newly build churches in the 1950`s and 60`s, the number of maintenance actions inevitably shows a sharp increase corresponding to the critical period of 30 – 40 years after the construction year [Boss08].

According to the total of 824 church buildings and the aim to balance the entire asset in a 40 year maintenance life cycle the church needs to accomplish an annual average of ca. 42 maintenance measures in future. This suggests that the increased demand of maintenance actions in the past years is not only caused by the building boom of the 1950`s and 60`s but also an outcome of the insufficient number of maintenance actions accomplished in the years from 1950 to 1995.

In order to achieve a more precise impression on the “fictitious” age structure of the church asset, figure 7 shows the extraordinary maintenance measures for buildings that have had improvement actions in the past as well as the construction years for those buildings that did not have any recorded improvement actions yet.

The graph therefore displays a combination of fictitious and real construction years.

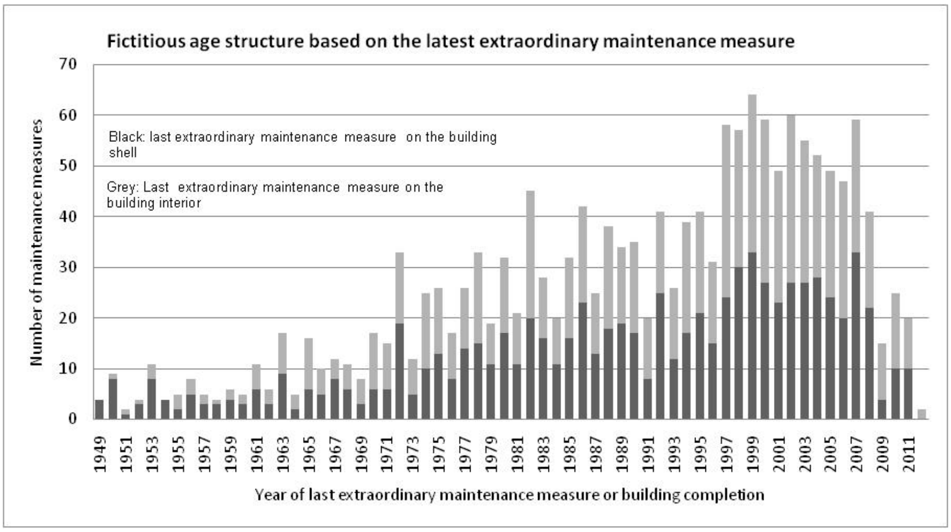

Figure 7: Fictitious age structure based on the latest important improvement measure

The fictitious age structure of the asset covers a period of 63 years. Consequently the 40-year maintenance life cycle has been considerably exceeded by numerous buildings. Exactly 180 of the total of 1648 documented maintenance measures were accomplished before 1971. This means that for up to 11% of all buildings a considerable maintenance backlog cannot be excluded.

4.3.2 Second Reallocation Based on a "Defined Time Interval of Exterior and Interior Measures"

The second reallocation is based on the requirement to balance the entire church schedule within a 40-year maintenance life cycle and on the demand to generate a defined interval between the maintenance measures on the building shell and interior. Therefore those 180 church buildings which were identified to have at least one extraordinary maintenance measure, that dates back before 1971 need to be integrated in the 40 year life cycle. Furthermore the newly defined interval had to be taken into account.

In the past, 53% of the church buildings have had their maintenance measures to the interior and the building shell carried out at the same time, while for 47%, the maintenance activities to the interior and the building shell were accomplished at different times. The Protestant Church generally wants to pursue carrying out maintenance work to the interior and the building shell independently in the future, but strongly requests that the time interval should not exceed 10 years. The 10-year limit guarantees the timely realization of both kinds of maintenance activities to keep the building shell and interior in a fairly similar state throughout the full maintenance cycle.

The following examples illustrate the approach of the second reallocation using several data set constellations.

Case 1.0

The last important maintenance measures to the interior and to the building shell were carried out after 1971 and in the same year. Method: The years for which extraordinary measures are recorded are taken and reallocated, with the data set being integrated into the new strategic order via the addition of a 40-year maintenance cycle.

Case 1.0	built	Latest improvement measure		Fictitious improvement measure		Strategic reallocation	
ID		shell	interior	shell	interior	shell	interior
01.0055.0186.1	1740	1994	1994	1994	1994	2034	2034

Case 2.0

Since the construction of the building (after 1971), no important maintenance measure to the interior or building shell has been carried out or documented. Method: As no extraordinary measure has been carried out, the construction year serves as a basis for the reallocation. The data set is integrated into the new strategic order via the addition of 40 years.

Case 2.0	built	Latest improvement measure		Fictitious improvement measure		Strategic reallocation	
ID		shell	interior	shell	interior	shell	interior
01.0053.2062.1	1976	-	-	1976	1976	2016	2016

Case 2.1

Since the construction of the building (before 1971), no important maintenance measure to the interior or building shell has been carried out or documented. Method: As no extraordinary measure has been carried out, the year 1972 serves as a basis for the reallocation. The data set is integrated into the new strategic order via the addition of 40 years.

Explanation: Following the 40-year cycle, a maintenance measure should have been carried out in 2008. To date, no such measure has been realized. This is why the respective measure should be carried out in the very near future (2012). The fictitious year is hence set to 1972.

Case 2.1	built	Latest improvement measure		Fictitious improvement measure		Strategic reallocation	
ID		shell	interior	shell	interior	shell	interior
01.0017.0213.4	1968	-	-	1972	1972	2012	2012

Case 3.0

The latest important maintenance measures to the interior and to the building shell took place in different years (difference > 3 years). The earlier measure took place after 1971. Method: For a difference of < 30 years, the date of the latter measure is antedated by half of the difference in years between the second and the first measure minus the desired delta of 10 years (MM_latter – MM_earlier – 10 years) * 1/2, while the date of the first measure is postdated by the same number of years. The resulting data set is integrated into the new strategic order via the addition of 40 years.

Case 3.0	built	Latest improvement measure		Fictitious improvement measure		Strategic reallocation	
ID		shell	interior	shell	interior	shell	interior
01.0055.2965.2	1447	1975	1996	1980	1990	2020	2030
01.0045.2520.1	1150	2006	1988	2002	1992	2042	2032

Case 4.0

The basic line-up is nearly identical to case 4.0, only the time difference of both maintenance measures is 3 years or less. Method: Due to the little time interval between both measures, these will be plant for the same year in the future. As a basis serves the average of both years (decimals are round up). The resulting data is integrated into the new strategic order via the addition of 40 years.

Case 4.0	built	Latest improvement measure		Fictitious improvement measure		Strategic reallocation	
ID		shell	interior	shell	interior	shell	interior
01.0053.2044.2	1500	1985	1988	1987	1987	2027	2027
01.0055.2962.1	1793	2004	2003	2004	2004	2044	2044

Case 5.0

The basic line-up is nearly identical to case 3.0, but with one of the maintenance measures dating from a year before 1971. Method: As in case 2.1, the year of the measure carried out before 1971 is antedated to 1972 and integrated as 2012 into the new strategic order via the addition of 40 years. At the same time, the second measure is integrated into the new strategic order either as 2022 (if the real date was before 1996) or 2042 (if the real date was after 1996), or 2052 (if the real date was after 2004).

Case 5.0	built	Latest improvement measure		Fictitious improvement measure		Strategic reallocation	
ID		shell	interior	shell	interior	shell	interior
01.0053.0659.1	1727	1963	1985	1972	1985	2012	2022
01.0054.1030.4	1862	1963	2002	1972	2002	2012	2042
01.0052.2456.1	1770	2005	1970	2005	1972	2052	2012

Case 6.0

Only one date is recorded for the last important maintenance measure. Method: Regarding the known date, the method follows the description of case 1.0 or 2.1 (if the date of the measure is before 1971). For the measure that has not been carried out, the same procedure as described for case 2.0 or 2.1 is followed (if the construction year is before 1971). The further procedure of integration into the new strategic order corresponds to the description of case 5.0.

Case 6.0	built	Latest improvement measure		Fictitious improvement measure		Strategic reallocation	
ID		shell	interior	shell	interior	shell	interior
01.0015.3056.4	1977	1998	-	1998	1977	2047	2017
01.0054.1616.1	1974	-	2003	1974	2003	2014	2044

Figure 8 illustrates the result of the 2nd reallocation and visualizes the number of required extraordinary maintenance measures per year for the coming 4 decades. For the first time, all 824 church buildings were included in a 40-year maintenance cycle.

The distribution of the measures per year, however, remains quite inhomogeneous. Especially for 2012 (212 measures scheduled) and 2042 (125 measures scheduled), the number of measures considerably exceeds the desired average of 40 – 45 measures (represented by the dotted 42-year line).

The majority of the years 2013 - 2021, and 2022 – 2036, however, remain below the desired number of measures. The extreme peaks in 2012 and 2042 are due to the fact that during the 2nd reallocation, all measures dating from before 1971 were postdated to 2012 for the current maintenance cycle (see case 2.1).

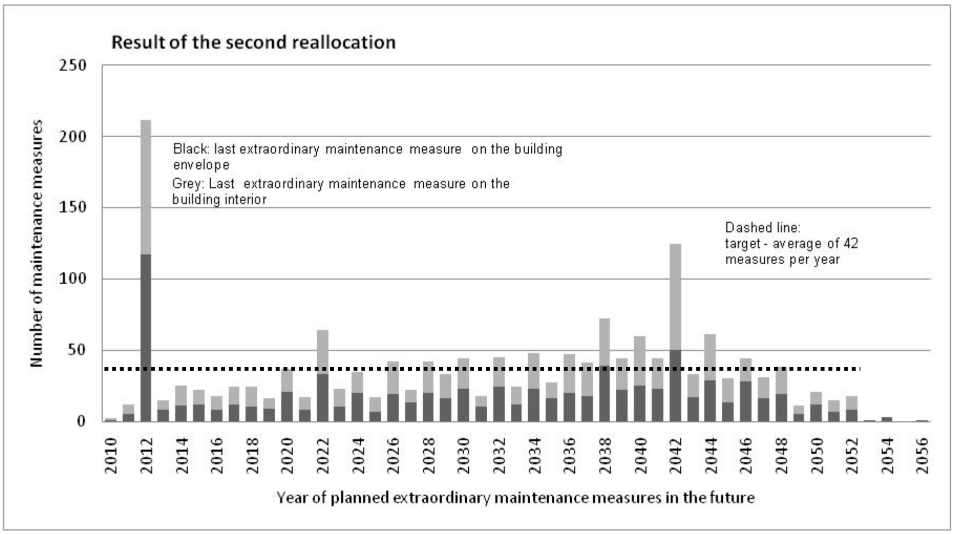

Figure 8: Overview of future improvement measures after the 2nd reallocation

The idea behind this is that the latest measures documented were carried out more than 40 years ago and therefore, a new improvement measure is overdue. The high number of extraordinary maintenance measures before 1971 thus leads to peaks in 2012 and 2042. In order to further balance the complete 40-year maintenance cycle and to smooth out or remove peaks, another reallocation becomes necessary.

4.3.3 Third Reallocation Based on the Validation of the Building Condition

The 3rd reallocation of church buildings is based on the validation of the building condition of the church buildings provided by the Protestant Church in Baden. This validation is done with the help of condition grades, from 1 (very good condition) to 5 (insufficient condition). In a first step, all measures scheduled for 2012 after the 2nd reallocation are validated one by one and assigned a condition grade. The rating ranges from 2 (good) to 5 (insufficient). The reallocation was done following the case-method described below.

Table 1 Definition of the Case-Method

Case A	Case B	Case C	Case D	Case E
The building condition (interior or shell) has not been assigned a grade.	The building condition (interior or shell) was assigned grade 5 (insufficient).	The building condition (interior or shell) was assigned grade 4 (sufficient).	The building condition (interior or shell) was assigned grade 3 (satisfactory).	The building condition (interior or shell) was assigned grade 2 (good).
Due to the low number of cases (9% of all church buildings concerned), the respective measures are scheduled for 2012.	The required measures need to be carried out urgently and are therefore scheduled for 2012.	The required measures need to be carried out as soon as possible and are therefore scheduled for 2012 and 2013.	The required measures need to be carried out in the near future and therefore scheduled for 2013 - 2016.	The required measures need to be carried out in the medium term and are therefore scheduled for 2017.

The following principle applies to all cases: Buildings whose latest improvement measure was carried out earlier (e.g. 1950) are scheduled earlier than buildings whose latest measure e.g. only slightly exceeds the 40-year cycle (e.g. 1969). Those measures which would have been scheduled for the years 2013 to 2018 according the 40-year maintenance cycle are carried out at a later date due to the cases A-E and packed into the years 2018 – 2020. This method guarantees the maintenance of all church buildings in order of priority and leads to an optimized annual distribution of maintenance measures over the full cycle for the years 2012 – 2020.

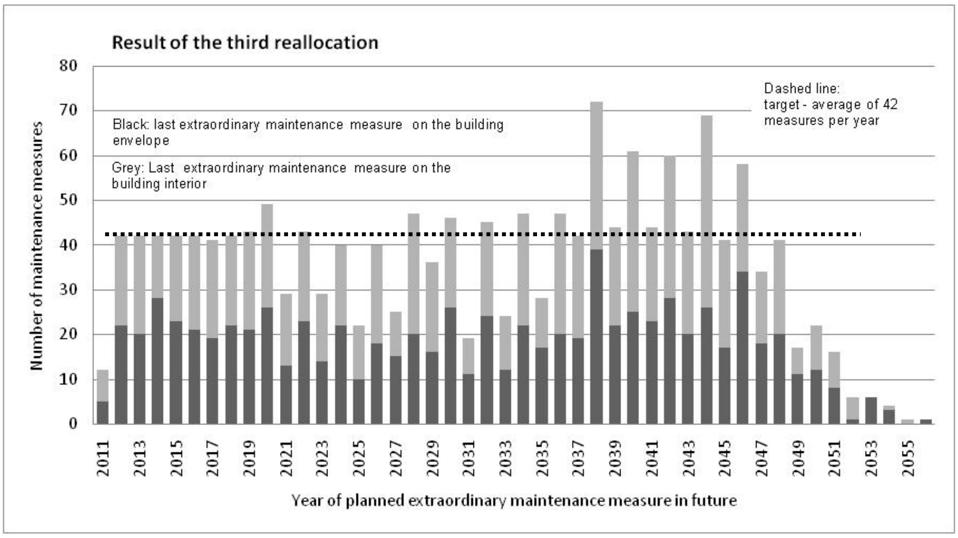

Figure 9: Overview of future improvement measures after the 3rd reallocation

The reallocation of all improvement measures scheduled for 2012 according to condition grades helps to considerably smooth out the peaks seen before (2012 and 2042) and to evenly distribute the number of measures between 2012 and 2020. The new distribution leads to a projected number of 40 – 43 measures per year for the upcoming 8 years. The period from 2021 to 2037, however, remains very inhomogeneous regarding the number of measures. On average, the number of planned measures for the period between 2021 and 2037 is considerably lower than the future objective. On the contrary, the average number of measures scheduled for the period between 2038 and 2048 is considerably higher, as the number of measures scheduled per year nearly always exceeds 42. 2038 represents the peak with 72 measures. Against this background, the potential for further harmonization needs to be analyzed.

4.3.4 Fourth Reallocation – Potential for Further Harmonization

While the upcoming decade has been smoothed out via the 3rd reallocation, the period between 2020 and 2051 remains considerably inhomogeneous regarding the number of measures per year (19 to 72 measures). The period between 2020 and 2037 remains under average and the period between 2038 and 2051 exceeds the average by far. The aim of the 4th reallocation of church buildings is to reach balance across all years of the future 40-year maintenance cycle. To this end, the following method was applied:

Within a period of low maintenance activity (2020 to 2037), the measures were antedated depending on the year of the latest extraordinary measure combined with the building validation (condition grade). Example: In order to raise the number of measures from the 29 measures scheduled for 2021 to 42, the measures scheduled for 2022 are put in order depending on their date and condition rating. The buildings with the earliest extraordinary measure and the worst condition grade are antedated to the year 2021, until the desired number of 40 – 43 measures per year is reached. This procedure is repeated for each year. If antedating is not possible, because the previous year has already 42 measures scheduled, and the current year exceeds the objective of 42 measures, the method is slightly altered: After the data has been structured according to school grade and date, the buildings with the best validation result and latest extraordinary measure are postponed to the following year.

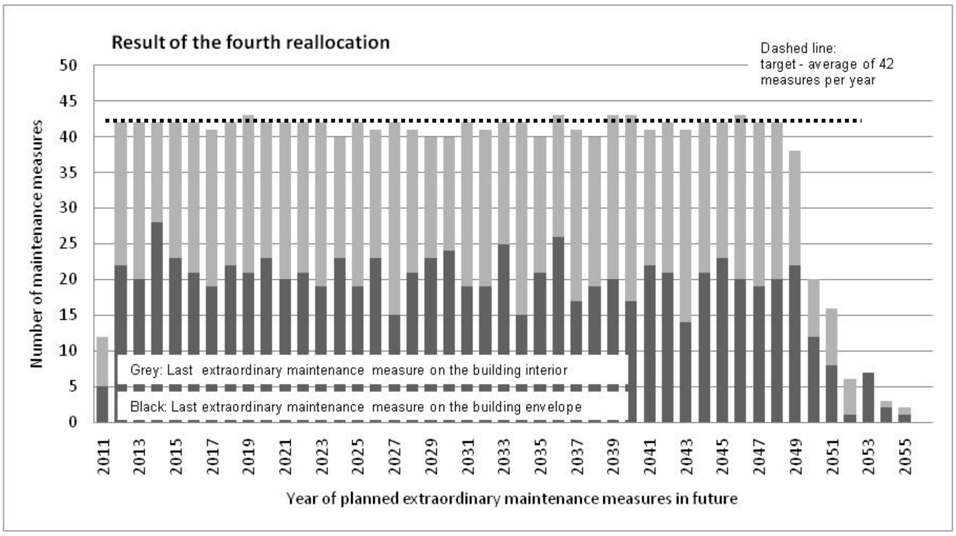

Figure 10: Overview of future improvement measures after the 4th reallocation

The basic idea behind this antedating and postdating is the assumption that no harm is done if buildings in a bad condition are renovated 1 to 2 years earlier as required by the maintenance cycle, while buildings in a good condition should be able to wait up to 2 years longer than intended by the maintenance cycle. Thus, under-average years can take on more measures and over-average years can be relieved.

The method described leaves the schedule almost completely balanced with 40 – 43 measures scheduled for each year of the 40-year maintenance cycle. The ratio between extraordinary measures to building shell and interior only varies slightly. Peaks appear in 2014 (28 measures to building shell / 14 measures to interior) and 2043 (14 measures to building shell / 17 measures to interior). For the majority of the 40 years, however, the distribution is even. As the balanced final distribution shows, reallocation is possible.

5 CONCLUSION

The results of the study show that it is possible to balance a large built asset by reallocation using the fictitious construction year, the latest extraordinary improvement measure (building shell and interior) as well as the building validation (via condition grades). Of course the process displayed is just a first exemplary approach to balance schedules and budgets but the reallocation steps used are predominantly simple and applicable to other assets as well. The reallocation of the asset is primarily based on generic building information and different operation standards that might be generated for any kind of asset. Yet the balancing process described is focused on the results of research projects that were solely done in Germany. It is therefore not possible to predict whether the procedure can also be adopted for foreign assets. It is likely that different adjustments probably would become necessary.

But the resulting comprehensive overview of all extraordinary maintenance measures over the complete 40-year cycle provides the maintenance specialists in Germany with a reliable basis for maintenance management. For the Protestant Church in Baden, the results described give a transparent and clear picture of the position in time of each congregation within the overall church maintenance process in terms of the extraordinary maintenance measures. This makes it a particularly useful tool for medium- and long-term maintenance planning and also reduces the costs for building evaluations. Based on the comprehensive overview only the buildings scheduled to have an extraordinary measure in the upcoming years need to be evaluated, whereas the effort to evaluate the other buildings might be significantly reduced.

Generally the balanced schedule gives maintenance experts a good basis to plan their maintenance actions in terms of financial expenditures as well as human resources to accomplish the tasks. Nevertheless the schedule should not be operated as a fixed structure. Not all of the buildings in the asset for instance will always apply exactly to the 40 year maintenance life cycle. There might be individual cases that need exceptional attention. Therefore the future planning based on the harmonized schedule still needs some planning flexibility taken into account. Furthermore there are additional risks that naturally cannot be foreseen, for example new political guidelines, climate change or environmental disasters. If any of these occur, the schedule would have to be completely renewed.

Yet for many owners of large built assets a balanced schedule as described is a very good start to optimize their building maintenance. Putting up the schedule forces the experts to structure their entire asset, get aware of problems that need to be addressed and develop a first strategic plan to accomplish the future maintenance. Because even today there is still a big number of large asset owners in Germany who still have not started to maintain their asset in an adequate professional and long-term orientated way. Therefore building up a balanced maintenance schedule including all of the buildings owned, is a first step in the right direction.

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