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Online retrofit catalogue and webtool for large-scale seismic upgrading

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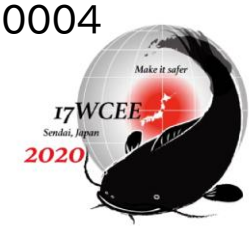
Abstract

In the Netherlands seismic hazard has been typically considered as very low. However, due to exploitation of large on-land gas reservoirs shallow earthquakes up to expected magnitudes of about 5 Mw may be induced in the North-Eastern region of the Netherlands (Groningen). According the 'National Coordinator Groningen' (NCG), 23.5 thousand houses are at risk. The potential compromised safety and social distress among the inhabitants demanded a quick response from the Dutch government. The government hired various engineering firms to assess the safety of buildings and to propose strengthening measures if required. Until recently, the process of retrofitting was performed manually at the different firms, requiring labour-intensive and time-consuming processes for each building at risk. The results of these assessments and proposed retrofit designs varied strongly amongst the various operating firms. In order to speed up the strengthening process and to ensure uniform results, Royal HaskoningDHV developed a Catalogue of retrofit measures.

The Groningen Measures Catalogue "GMC", is an online platform to enable co-creation and exchange of expertise and experience across companies. It includes +200 standardised retrofit measures tailored for the buildings in the earthquake-prone Groningen area. All measures are described upon various aspects such as the strengthening objective, structural safety/improvement, material specifications, health & safety, impact on aesthetics, costs, etcetera. The measures are classified on performance indicators using a simple ranking system. When a measure is applied, the experiences of the contractor and construction workers is collected and implemented in the catalogue. This enables a self-improving process and an improved characterisation of the measures based on practical experience. The measures in the catalogue are in varying stages of development. The Technical Readiness Level "TRL", is a parameter in the catalogue that states the level of development of a retrofit measure. The development of the retrofit measures is achieved in collaboration with various engineering firms, the construction industry, universities and the local authorities. Currently, over 50 parties are working with the online GMC.

In cooperation with web developer Freshheads the website 'www.maatregelencatalogus.nl' was developed. This website contains both the GMC and a webtool. The webtool visualises the considered building with a 3d-model. Based on the characteristics of the building and the output of the structural assessment, the webtool filters and selects the suitable solutions from which the structural engineer is able to compose a tailored retrofit design. In the next step, the cost expert uses the webtool to estimate the strengthening cost. To a large extend this is an automated process. Subsequently the output of the website is used to collect data to report to the building owners. The use of the GMC and webtool ensures uniform results, creates uniform data collection and enables a significant acceleration of the strengthening process and an effective stakeholder involvement.

Keywords: Retrofit design; standardised measures; retrofit catalogue; webtool



1. Introduction

In the design of typical Dutch buildings, the potential impact of earthquakes is not taken into account. The seismic hazard in The Netherlands has typically been considered as very low. However, due exploitation of gas fields, shallow earthquakes up to expected magnitudes of about 5 Mw may be induced in the North-Eastern region of the Netherlands (Groningen); occasionally causing non-structural damage. According the 'National Coordinator Groningen' (NCG), 23.5 thousand houses are at risk [1]. The potential compromised safety and social distress among the inhabitants demanded a quick response from the Dutch government.

Various parties were involved in a large-scale upgrading project in which the safety of buildings has to be assessed. If required, strengthening measures are being proposed. The assessment of buildings, designing strengthening measures and erecting strengthening requires the expertise and input of multiple stakeholders: amongst others structural engineers, construction workers who are actually strengthening the structures and also the inhabitants.

Initially the involved parties started to work on their own sub-assignment in a conventional building process. This approach had various downsides which are described concisely below.

1.1 Inefficient research process

Due to the low seismic activity in the Netherlands the majority of the building industry has few or no experience with designing and building earthquake-resistant buildings. Additionally, typical Dutch buildings are not compliant with typical requirements as described in guidelines on seismic resistance [2], to achieve sufficient seismic resistance. It was required to perform extensive research to the effect of seismic load on buildings with a typical Dutch typology (often consisting of unreinforced masonry walls and timber floors). The stakeholders individually struggled with finding answers on similar research questions. Results of their research were not well-documented and collected on a shared platform. Therefore, the initial research process proved to be slow and inefficient.

1.2 Labour-intensive process

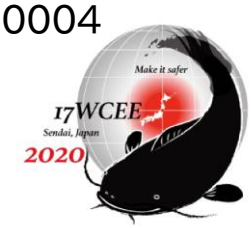
The engineering firms started up labour-intensive processes for each building at risk. Assessing and retrofitting every building with a conventional process whereby every building is individually assessed would take decades.

1.3 Different firms found varying solutions

The results of the assessments and proposed retrofit designs varied strongly among the various operating firms. This was exemplified by the observation that the analysis of two similar buildings assessed by different engineering firms often resulted in completely different outcomes. These differences enlarged the social distress among the inhabitants.

1.4 Built-in structured learning effect (continuous and collective learning curve)

A design is made by an engineer and the design is being built by a contractor. Within a conventional building process the erection of the design is managed by an engineer. This does not have to be the same engineer that designed the building. However, if a retrofit measure is applied, it is of importance that the proposed measure is reviewed using the practical experience of the construction workers involved. Can the structure be erected as it was drawn? Is the measure easy to apply? Does the strengthening design cause lot of additional work? The experience of the contractor is a valuable input for all engineers and their follow-up projects.



2. GMC-catalogue

In order to speed up the strengthening process and to ensure uniform results, Royal HaskoningDHV an independent international engineering and project management consultancy developed a Catalogue of retrofit measures.

The Groningen Maatregelen Catalogue "GMC", is an online platform to enable co-creation and exchange of knowledge and experience across companies. It includes standardised retrofit measures tailored for the buildings in the earthquake-prone Groningen area. The measures are described upon the following fifteen aspects: strengthening objective, detailing, execution (description of implementation), field of application, material specifications, structural improvement, prove of structural safety (strength/stiffness value), practicality, health & safety, impact on spatial quality, impact on aesthetical quality, cost, additional proceedings, architectural consequences and additional points of attention.

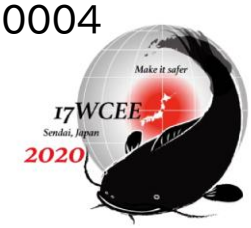
The development of the retrofit measures is performed in conjunction with various engineering firms, the construction industry, universities and the local authorities. Over 50 parties are currently or have been working with the online GMC.

2.1 Catalogue levels

After the structural assessment of a building some structural deficiencies might be found. Each deficiency applies to a different part of the building. All retrofit measures in the catalogue are developed to solve a specific structural deficiency. In order to use the catalogue well, the measures are arranged in the following 'measure levels':

Table 1 – The measures in the catalogue are arranged in different measure levels. Each measure level has its own colour

Level	Name	Description	Colour
1	Potential building elements at risk	Measures for building elements that require an immediate action. This contains for example a measure to remove a slender chimney and replace it with a lightweight alternative.	Dark blue
2	Connections	Measures to connect of improve the connections between different building elements. For instance, improve the connection between a wooden floor and a masonry wall.	Blue
3	Floors and roofs	Measures to improve diaphragm capacity of floors and roofs	Green
4	Walls out-of-plane	Measures to improve out-of-plane capacity of walls	Orange
5	Walls in-plane	Measures to improve in-plane capacity of walls	Red
6	Foundations	Measures to improve the bearing capacity of the foundation	Dark green
7	Demolish	(Partly) Demolish a building	Black
8	Change of structural system	Adding dampers or base isolation	Purple



2.2 Technical Readiness Levels

The measures in the catalogue are in varying stages of development. The Technical Readiness Level "TRL", is a parameter in the catalogue that states the level of development of a retrofit measure. This rating system is based upon the Technology Readiness Level developed by NASA [3]. The TRL in the GMC grades from TRL1 to TRL7. When a strengthening measure is proposed and the resulting objective is described, it is marked as TRL1. The TRL levels are elaborated in Table 2.

Every user of the catalogue is allowed to propose new measures using a simple template. The proposal is assessed by an experienced review committee with representatives (seismic structural experts) from different companies. Firstly, the committee checks if the proposed measure is of added value for the catalogue. If so, the measure is included in the catalogue. Secondly the TRL of the measure is determined based on the requirements of Table 2.

Table 2 –Technical Readiness Levels

TRL	Stage	Description
1	Proposal	When a new strengthening measure is proposed and both the engineer and contractor agree it is of added value
2	Structural feasibility approved	A structural calculation proved the structural feasibility
3	Execution feasibility approved	The execution method is elaborated, and the contractor is convinced that it can apply the measure
4	Integral design approved	The measure is elaborated for an example project and satisfies the requirements upon all aspects. The level of elaboration is similar with the level of a final design
5	Elaborated in a specific project	The measure is elaborated for a specific project and is ready to be executed
6	Applied in a reference project	The measure has been applied in a project. The implementation has been evaluated and the measure is improved based upon this input
7	Applied in multiple projects	The measure has been applied, evaluated and improved based upon the application in multiple projects.

2.3 Evaluation of Measures

When a measure is applied, experiences of the contractor and construction workers are collected and implemented in the catalogue. This allows a progressive gain of knowledge resulting in an improved characterisation of measures based on practical experience. The implementation measure L4-F is shown in Fig. 1. The L4-F measure consists of timber beams mounted to the wall in order to improve the out-of-plane capacity.

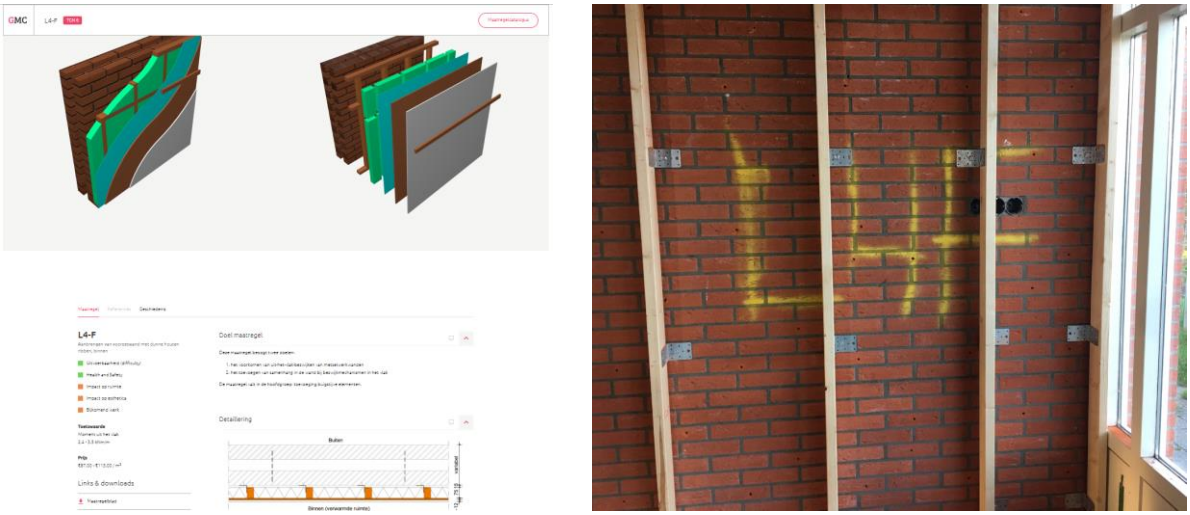
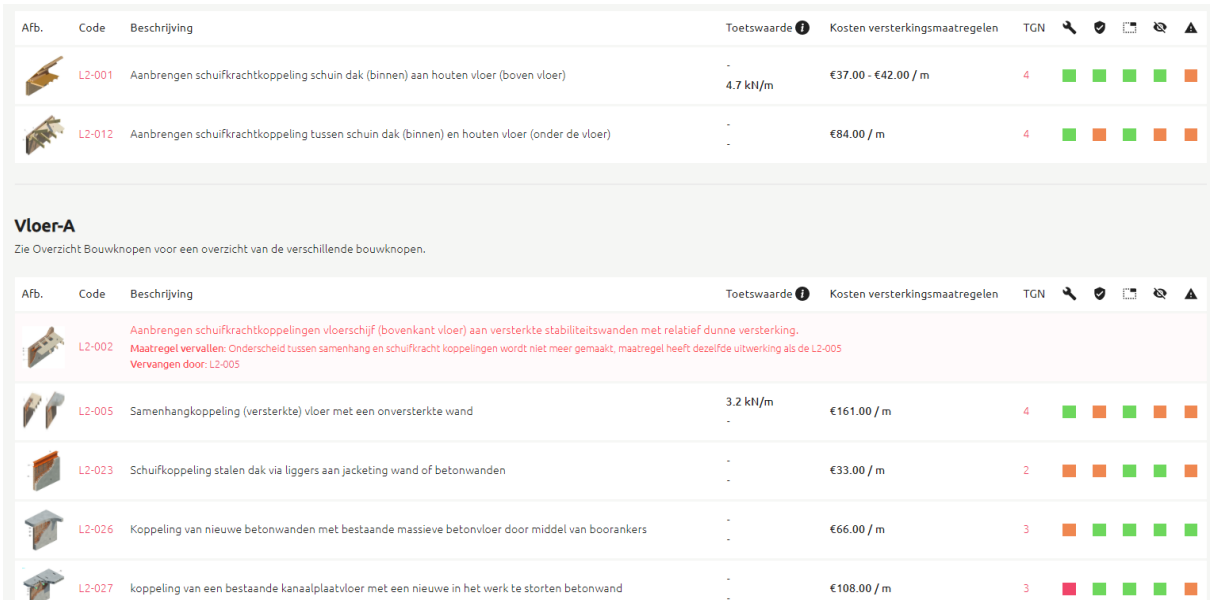


Fig. 1 – Measure L4-F; depicted at the GMC-website (left); on construction on site (right)

2.4 ‘Traffic Lights’

The measures are compared to each other by a simple ranking system. This ranking system consists of a colour code rating system on the following five aspects; Practicality (difficulty), Health and Safety, Impact on living space, Aesthetical impact and Additional work required for execution. The ranking system gives the user insight in the possible consequences of the measure. A green rating means: easy to apply, limited to no extra work required to apply the measure. An orange rating: possible difficult to apply, depending on the local situation and other measures that are to be applied. A red light means: high impact, the measure is not a desirable solution and should only be used when no alternative is available. In Fig. 2 a section of the measure catalogue is shown in a screenshot of the GMC website. The traffic lights are shown in the columns on the right.



Afb.	Code	Beschrijving	Toetswaarde	Kosten versterkingsmaatregelen	TGN
	L2-001	Aanbrengen schuifkrachtkoppeling schuin dak (binnen) aan houten vloer (boven vloer)	- 4.7 kN/m	€37.00 - €42.00 / m	4
	L2-012	Aanbrengen schuifkrachtkoppeling tussen schuin dak (binnen) en houten vloer (onder de vloer)	- -	€84.00 / m	4

Vloer-A

Zie Overzicht Bouwknopen voor een overzicht van de verschillende bouwknopen.

Afb.	Code	Beschrijving	Toetswaarde	Kosten versterkingsmaatregelen	TGN
	L2-002	Aanbrengen schuifkrachtkoppelingen vloerschijf (bovenkant vloer) aan versterkte stabiliteitswanden met relatief dunne versterking. Maatregel vervallen: Onderscheid tussen samenhang en schuifkracht koppelingen wordt niet meer gemaakt, maatregel heeft dezelfde uitwerking als de L2-005 Vervangen door: L2-005			
	L2-005	Samenhangkoppeling (versterkte) vloer met een onversterkte wand	3.2 kN/m -	€161.00 / m	4
	L2-023	Schuifkoppeling stalen dak via liggers aan jacketing wand of betonwanden	- -	€33.00 / m	2
	L2-026	Koppeling van nieuwe betonwanden met bestaande massieve betonvloer door middel van boorankers	- -	€66.00 / m	3
	L2-027	koppeling van een bestaande kanaalplaatvloer met een nieuwe in het werk te storten betonwand	- -	€108.00 / m	3

Fig. 2 – Section of the measure catalogue. The description of the measures is given in the overview. Besides a small thumbnail picture of the measure, the measure code, the structural capacity, the building costs, the TRL and the ‘Traffic Lights’ ratings are given.

3. Webtool

In cooperation with web developer Freshheads the website 'www.maatregelencatalogus.nl' was developed. The front page of the website is depicted in Fig. 4. The website consists of two parts: the GMC-catalogue as described in chapter 2 and the webtool. This has been depicted in Fig. 3. Within the webtool the user can upload a 3d-model (via IFC format) of the considered building. The webtool visualises the considered building and allows individual elements to be selected and to show the related data. Within the webtool a tailored retrofit design with the preselected measures can be composed by a multidisciplinary team. Uniform documentation and data-collection output is ensured of and generated automatically. This results in a proven acceleration of the strengthening process.

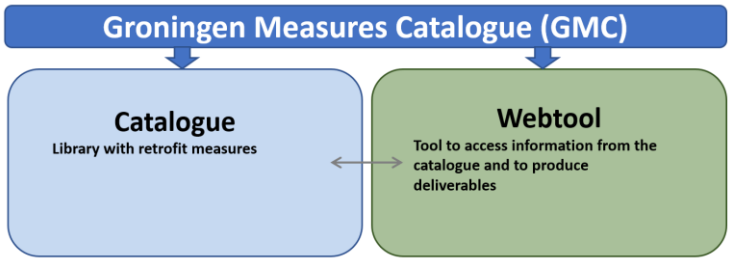


Fig. 3 – The GMC website consists of both the catalogue and a webtool

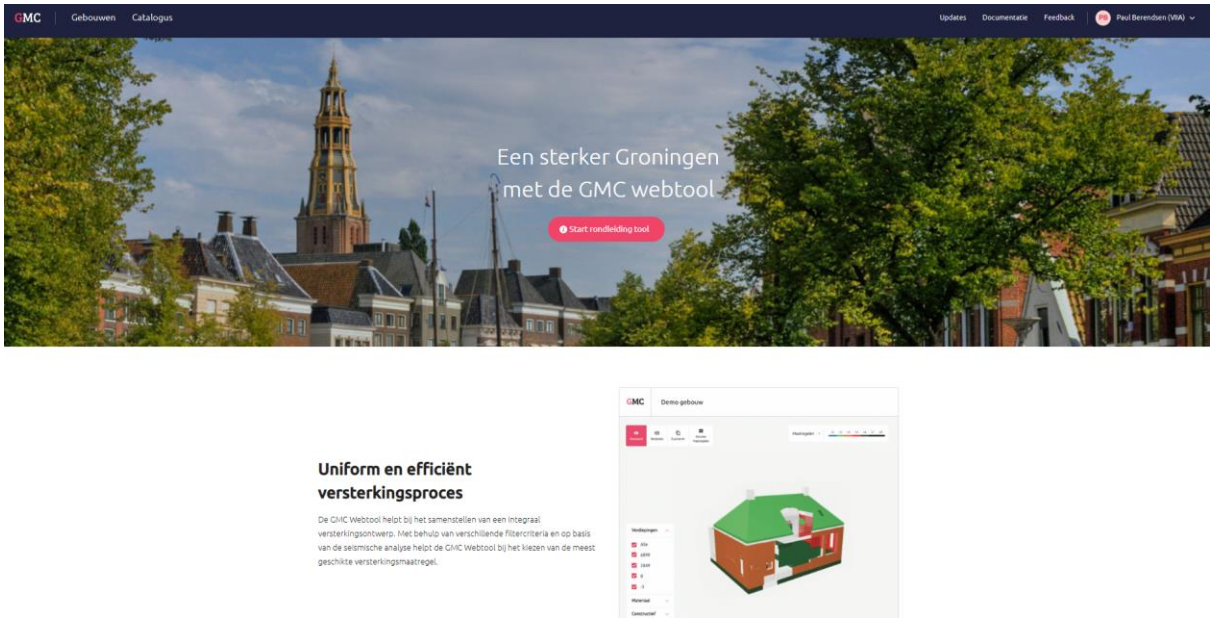


Fig. 4 – Homepage of the GMC-website

3.1 Retrofit Process

The retrofit process of a building consists of several stages. In Fig. 5 the stages where the webtool supports the process are depicted in the grey-coloured circles. The analysis and assessment process is connected to the webtool via data exchange. Subsequently the output of the website is used to collect data and to report to the building owners. The different stages of the process are elaborated in Table 3.

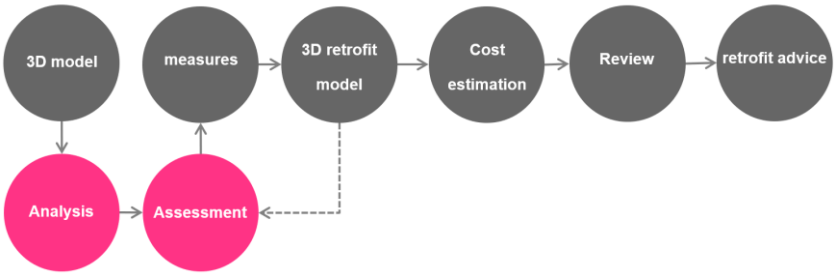
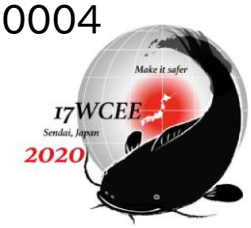


Fig. 5 – Items depicted in the grey-coloured balls are covered by the Webtool

Table 3 – Several stages of the retrofit process that are included in the webtool

Stage	User	Description
3d-model	Engineer or draftsman	Within the webtool the user can upload the 3d-model (in IFC-format) of his building. The webtool visualises the considered building. Based on the characteristics of the building, the webtool filters and shows the suitable solutions available in the catalogue.
Measures	Structural engineer, cost expert, architect, contractor and a representative of the owner	If a building has several deficiencies a design team compiles an integrated retrofit design with measures from the GMC-catalogue. This happens during a design meeting where experts from various disciplines take part.
3d-retrofit model	Automated	When the engineer has selected the measures the webtool visualises the retrofit measures and shows all the locations of particular retrofit measures
Cost estimation	Cost expert	The cost expert uses the data generated by the webtool to estimate the strengthening cost. To a large extend this is an automated process.
Review	Internal of external	After the retrofit design is finalised the webtool offers the option of a review stage. Within this stage either an internal of external review can be done.
Retrofit advise	Automated	The reviewed retrofit design is ready and the webtool generates the following output documents: • Booklet with applied measures (PDF) • Measures applied as structured data (JSON) • Cost estimation (PDF)



3.2 Visualisation of building and upgrade requirements

The webtool is visualises the building. By clicking on a wall additional information about the building element is given. This enables the users to get clear insight in the building and the upgrading requirements. In Fig. 6 a screenshot of the webtool interface is depicted. Building elements that require a strengthening measure are automatically detected and shown in the interface. The colour corresponds with the measure-Level that is required.

The interface of the webtool is designed to visualise the geometry of the building including its characteristics, structural properties and the requirements of the building. This enables stakeholders to get a quick insight on the relevant building information. And this enables professionals to compose a tailored retrofit design consisting of standardised measures.

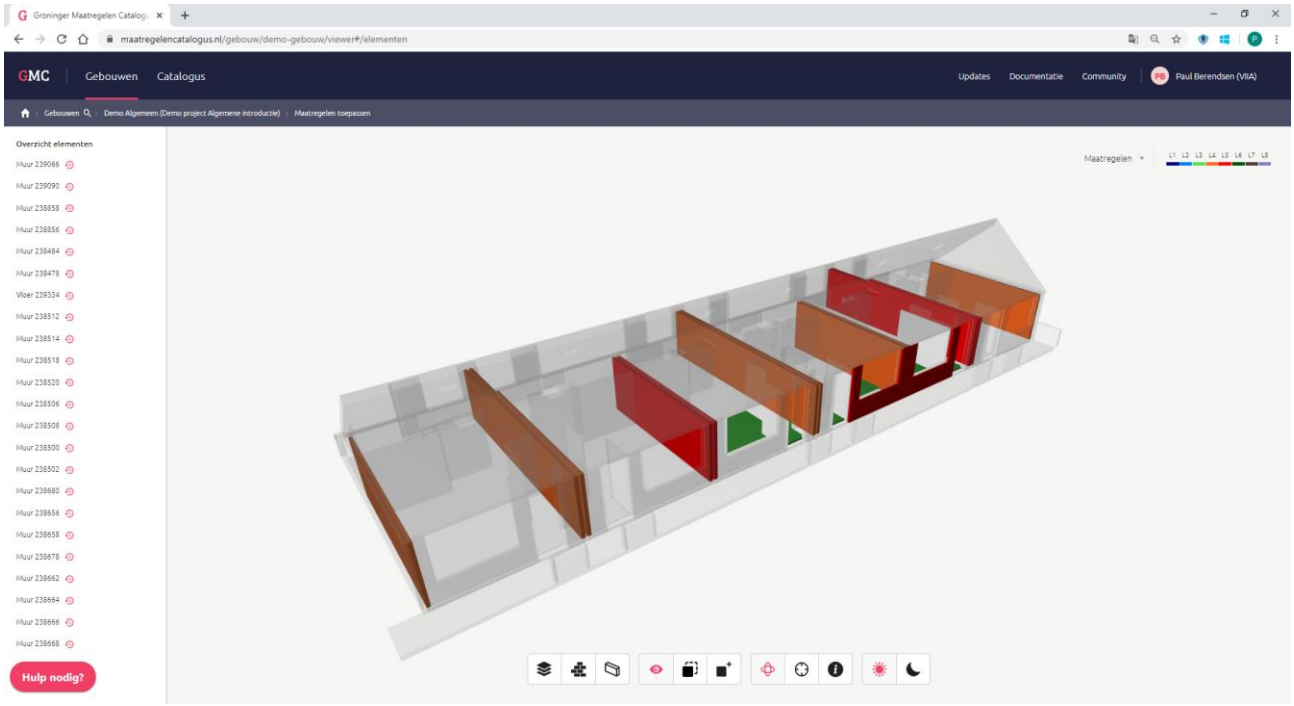


Fig. 6 – Screenshot of the webtool 3d-model showing building elements that require strengthening. The colours show the type (Level) of measure required

When an element that requires a strengthening measure is selected, the webtool filters and selects the suitable solutions based on the characteristics of the building element and the output of the structural assessment. In Fig. 7 a screenshot of the interface presenting the relevant measures for a certain building element is depicted.

After the measures are selected and the process in the webtool is finalised, output documents are generated automatically. One of the output documents is the Booklet with applied measures. As example a page of this booklet is depicted in Fig. 8. The entire description of a measure is available on the GMC website. The booklet provides the key information about the selected measures.

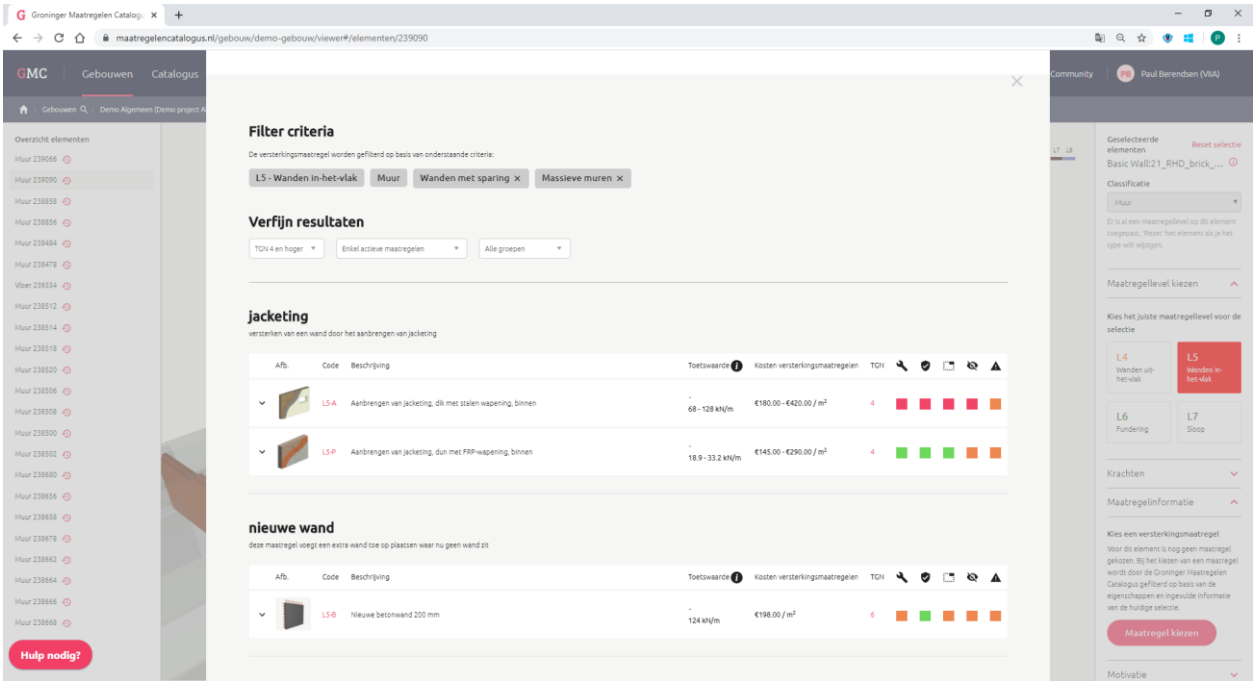


Fig. 7 – Screenshot of the webtool interface after selecting a building element that requires a strengthening measure.

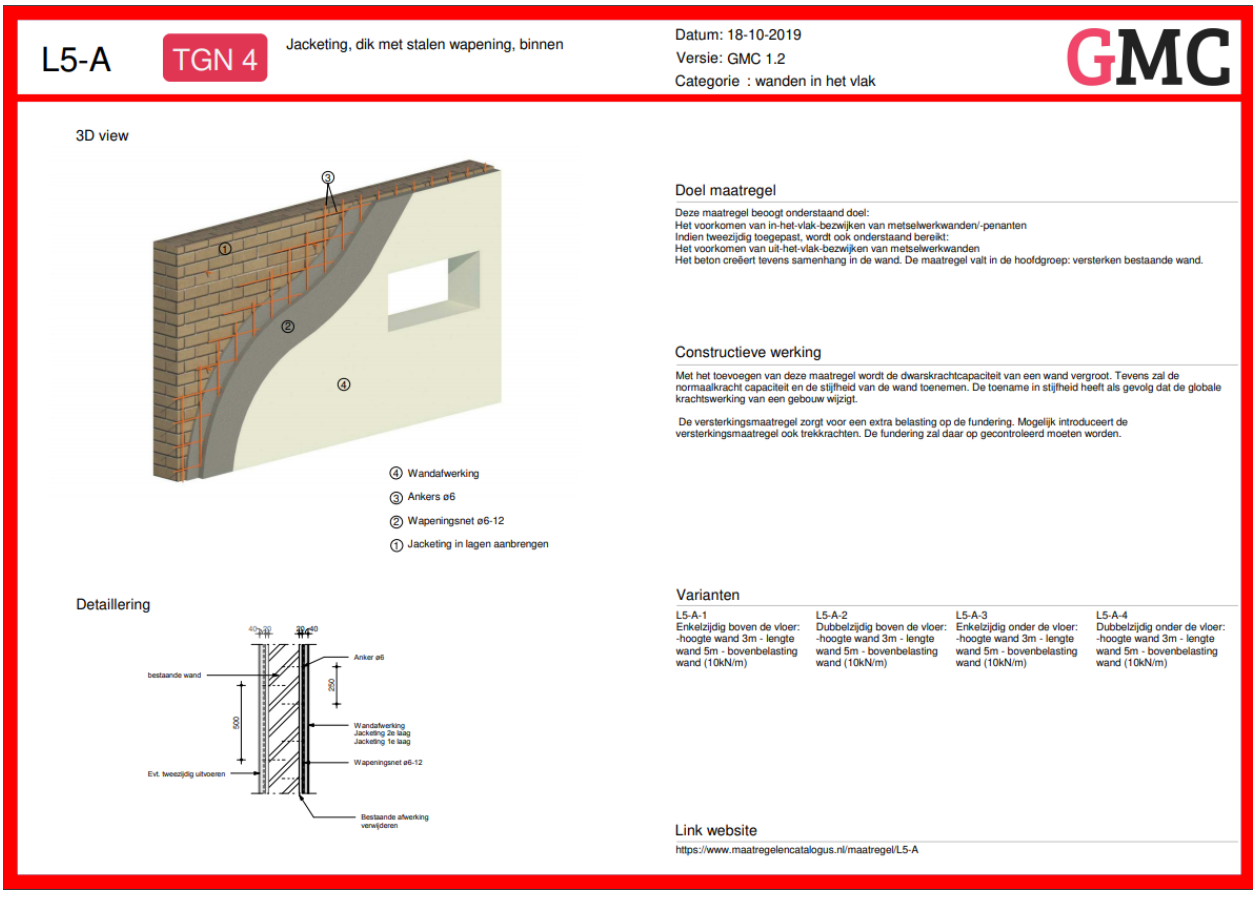


Fig. 8 – Example from the 'Booklet with applied measures' measure L5-A: a generic information sheet showing the essence

3.3 Showcase building

In the Groningen area one building has been converted into a showcase building. The added value of this building is twofold. Firstly, the building was intended to gain experience about the implementation of the measures. Secondly the building gives the opportunity to show the measures in reality both to the professionals involved as the inhabitants of the Groningen area. Two pictures of this building are provided in Fig. 9.

Fig. 9 – Measure L5-A (topside) and L4-J (bottom side) showcased. The measures are built up to show 'the inside' of a measure. This in order to explains the impact to the public and to gather feedback from professionals

4. Reference projects

Currently the GMC-catalogue and webtool are being used in the large-scale upgrading process in the North-Eastern region of the Netherlands. Within this upgrading project the use of the GMC has proven to be of added value. Firstly, the use of the catalogue resulted in research questions being investigated in cooperation between different parties instead of separated from each other. Also, research topics have been distributed among different parties improving the overall progress of the project. Secondly, the use of standardised measures significantly reduces the amount of work per building, in this way speeding up the project greatly. Thirdly, the use of standardised measures improved the uniformity between the various engineering and construction firms. Additionally, the webtool enables data collection in a uniform format, making the data more accessible for data analysis. Fourthly the lessons learned in a single project are added to the measure which prevents the same mistake being made again.

5. Conclusions

The approach as applied in the Dutch Groningen area shows that a shared and regulated platform speeds up the strengthening process, enhances co-creation between different stakeholders and ensures uniformity in data collection and deliverables.

The current catalogue and webtool as described in this article are tailored for the retrofit process in the Groningen area. The measures are tailored for the typical Dutch typology buildings and corresponding standards (NPR2018). Nonetheless the use of such a platform is applicable for all kinds of large-scale building challenges where multiple stakeholders are involved. For instance, seismic retrofitting for other earthquake-prone regions, or upgrading to sustainable housing. The platform allows for a combination of upgrades, such as combined energy-saving (insulation) and seismic strengthening measures; thereby widely expanding the possible applications for this platform.

6. References

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