An assessment tool for seismic strengthening of heritage buildings

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ABSTRACT: This research produced a multidisciplinary assessment tool to examine the effectiveness of seismic strengthening designs for heritage buildings. Fifteen one-on-one interviews of a range of experienced industry professionals were conducted using a grounded theory approach. This enabled the framework to be progressively refined throughout the research process. The resulting framework uses qualitative inputs to produce a table and spider graph presentation of the design's effectiveness across six assessment categories. These categories include heritage, seismic engineering, feasibility, architectural, services and fire protection, and buildability assessments. The spider graph is able to clearly communicate a design's effectiveness to stakeholders with limited technical knowledge. Original features of this study include a multidisciplinary framework that facilitates early collaboration, measures 'design performance' in relationship to 'client priorities', provides new assessment principles gleaned from industry knowledge, and provides a tracking tool as the design progresses through each developmental stage. It is hoped that this multidisciplinary framework will promote more successful design solutions via early and effective collaboration among project team members.

1 INTRODUCTION

1.1 Research Problem:

When a heritage building is identified as an earthquake-prone building (EPB), if the heritage 'fabric' and 'ambience' are to be safeguarded for future generations, then invasive strengthening work cannot be avoided. Seismic strengthening to heritage buildings is a challenging undertaking that requires a collaborative approach (Cattanach et al 2008). Cattanach et al. (2008, p. 9) attribute the success of an award winning retrofit design to the input of "a supportive, very experienced architecture and conservation team with whom the structure itself could be developed". This statement highlights the importance of early collaboration in heritage seismic strengthening projects. Forouzandeh and Malekshahi (2014) also strongly support the need for a multidisciplinary approach to seismic strengthening of heritage buildings. Forouzandeh and Malekshahi (2014, p. 177) explained that conservation of heritage buildings requires a "multidisciplinary approach involving a variety of professionals" and that a "close collaboration among structural engineers, architects and contractors in studying and [finding the] solution… is necessary".

While current literature emphasises the importance of early collaboration, and discusses various principles of effective seismic strengthening designs, there is a lack of a multidisciplinary assessment framework that encapsulates these principles or facilitates early collaboration. Therefore this research aimed to produce a multidisciplinary assessment tool to collaboratively examine the effectiveness of seismic strengthening designs for heritage buildings.

2 CURRENT ASSESSMENT FRAMEWORKS

This study examined several existing frameworks and various assessment principles for effective heritage strengthening designs.

First, Cattanach et al. (2008) aim to equip engineers with a framework to assess the appropriateness of retrofit methods in heritage EPBs. They presented a case study where they apply a qualitative framework to assess several intervention methods. Principles such as reversibility, transparency, and minimum intervention are used to critique various strengthening methods. The framework "is intended to be an assessment for just the structural intervention, and not the heritage impact of the whole project" (Cattanach et al 2008, p. 12). This is a crucial limitation because as Allaf and Charleson (2014, p. 6) state in their critique of the proposed framework: "despite greater consideration to the architectural qualities of a building, the appraisal framework remains limited…the architectural parameters are very general and need to be further developed and detailed".

Second, Allaf and Charleson (2014) propose a framework based on the format used for architectural design competitions. In this format the architectural qualities of a seismic strengthening design are critiqued against several main assessment criteria, each with various sub-criteria. The assessor enters both a written answer, similar to Cattanach et al. (2008)'s framework, and a numerical score rated from 1-5. The results are then displayed as a spider diagram to show the overall effectiveness of the design. While this framework provides a helpful format it stops short of providing a comprehensive set of assessment principles with which to assess a strengthening design, or the proposition of a multidisciplinary approach to the framework.

Third, McClean (2010) provides a helpful set of assessment criteria for appropriate strengthening of heritage EPBs. Each of the four criteria is broken down into a number of sub criteria. The four main criteria are:

- Sustainable management of historic heritage principles (e.g. respect for physical material and the degree that intervention is kept minimal)
- Alterations of historic building principles (e.g. not altering or removing important heritage fabric)
- Best practice engineering principles (e.g. considering existing strength inherent in existing structure)
- Other matters for consideration (e.g. cost, disruption to building occupants, space planning)

These criteria and their sub-criteria are helpful because they reflect current codes of practice and legislation. Although McClean (2010) provides a helpful set of assessment criteria, a framework with which to assess and compare strengthening designs is absent. Also, while it provides a wider range of assessment principles than other frameworks it remains limited in key areas such as buildability and feasibility. Additionally, principles are not categorised into various professional disciplines, such as architectural, seismic engineering, or construction fields, which is important for collaborative usability. While there is a clear acknowledgment in current studies that a multidisciplinary approach is required to successfully strengthen a heritage EPB (Cattanach et al 2008; Forouzandeh & Malekshahi 2014), a collaborative assessment framework that incorporates a holistic and comprehensive assessment is lacking. This research aimed to produce such a framework for assessing seismic strengthening designs.

3 RESEARCH METHOD

3.1 Research Approach

Grounded theory is the qualitative research approach selected for this study. It is an approach which seeks to use data collected to shape concepts rather than to prove or refute a theory or hypothesis. (Lacey & Luff 2007). Concepts or theories are discovered, shaped, modified, altered and validated in data and are therefore said to be 'grounded' in data (Hancock 2002). Advantages of using a grounded theory approach include allowing industry professionals and subject matter experts to have substantial input into the development of the framework, and then for this input to be critiqued by other professionals. This in turn helps to ensure industry relevance of the assessment tool. Fifteen semi-structured interviews were conducted as the primary data collection method. Six separate rounds of interviews were completed with each round involving several one-on-one interviews. After each round, interviews were transcribed and analysed, with the framework edited and updated throughout the research process.

3.2 **Participants**

Fifteen industry professionals were involved in this study, which included architects, heritage experts, civil engineers, services engineers, quantity surveyors, construction managers, and property developers. All participants had extensive industry experience with current or recent experience on strengthening of significant heritage buildings. 13 participants were in a senior management role, 10 each having more than 20 years industry experience, including 3 each having more than 40 years of industry experience.

4 **RESULTS**

4.1 **Assessment Categories and Sub Criteria**

The final revised framework consists of six main assessment categories; seismic engineering, heritage, feasibility, architectural, services and fire protection, and buildability. Each category has a maximum of ten sub criteria which are listed in detail below.

- 'Seismic Engineering' assesses the New Building Standard (NBS) percentage achieved, improvement of occupant and public safety, seismic compatibility with significant heritage fabric, minimum intervention, rediscovery or reinterpretation of traditional techniques, existing beneficial strength utilised, latest technology, and ease of post-earthquake recovery to NBS %.
- 'Heritage' assesses building use (maintain and enhance the existing use or discover a new use for the building), significant heritage fabric retained, significant heritage ambience retained, reversibility or removability of interventions, positioning of interventions in relation to high and low heritage value areas, intervention complimentary to heritage (eg hidden and discrete, or visible and transparent), respect for contents and surroundings, surface heights and levels maintained, retention of heritage views and sightlines, and level of restorative strengthening (repairs, maintenance or reinstatement possible during strengthening works).
- 'Feasibility' assesses acceptable overall project budget, the timeliness and program of works, value added and opportunities for enhancement, cost risk mitigation of proposed strengthening, acceptable knock on costs of strengthening, cost efficiency vs other possible designs, insurance premium savings, rental income retention during construction, acceptable cost of significant material selections, and whole life cycle cost savings (installation, operational and replacement costs).
- 'Architectural' assesses consentability, floor area and space circulation, impact on natural light, retention of views to and from the building, aesthetics of intervention, acoustic performance, thermal insulation, functionality of retained or reused items, and weather-tightness of the building envelope.
- 'Services and Fire Protection' assesses fire regulation compliance, impact on existing services infrastructure, incoming services capacity compatible with design, seismic performance of services, ability to integrate new services technology, energy efficiency, future proofing of services, and green star benchmarking.
- 'Buildability' assesses health and safety (safety by design and fire risk minimised), disruption to occupants minimised, availability of heritage trades, quality expectations achievable in design, simplicity of construction, ability to prefabricate interventions, building access to construct detailed interventions, significant material availability, sensible sequencing of works possible, and reduction of manual work.

4.2 **Workings of Assessment Framework**

The framework uses a Microsoft Excel template to qualitatively rank a proposed strengthening design against the various assessment criteria listed above. The qualitative ranking system involves simple drop down box selections, which through the use of a quantitative shadow table sets an average total rating for each assessment category. A spider graph is then populated with each of these average ratings to visually display the design's overall effectiveness as assessed against the client's priorities. The language and functionality of the ranking system was critiqued and developed to cater for industry professionals, but kept simple enough to be accessible to a wide range of stakeholders.

4.2.1 *Step One: Formation of Client Brief*

Because each heritage strengthening project is unique and requires a tailored approach a visual client brief is first built into the framework. This client brief provides a starting point for the project team to understand design priorities. The client works through the framework selecting a high, medium or low priority for each of the sub-criteria under each assessment category. The feasibility assessment category is shown in Figure 1 as an example of inserting the client importance level for each sub-criterion. Figure 2 displays the summary table that is populated once each assessment category is complete. The visual client brief appears as a red line in the spider graph, as illustrated in Figure 3.

FEASIBILITY	Timeliness/ Program duration of works	Value Added: opportunities for enhancement	Overall project budget acceptable	Cost Risk mitigation of proposed strengthening	Acceptable knock on costs of strengthening	Cost efficiency of strengthening vs other possible designs	Insurance premium savings	Rental income retention during construction	Acceptable cost of significant material selections	Whole life cycle cost savings. Installation, operational & replacement costs
DESIGN PERFORMANCE										
CLIENT IMPORTANCE LEVEL	HIGH	HIGH	MEDIUM	MEDIUM	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	HIGH

Figure 1

SUMMARY	SEISMIC ENGINEERING	HERITAGE	FEASIBILITY	ARCHITECTUAL	SERVICES & FIRE PROTECTION	BUILDABILITY
DESIGN PERFORMANCE						
CLIENT IMPORTANCE LEVEL	MEDIUM	MEDIUM	HIGH	MEDIUM	LOW	HIGH

Figure 2

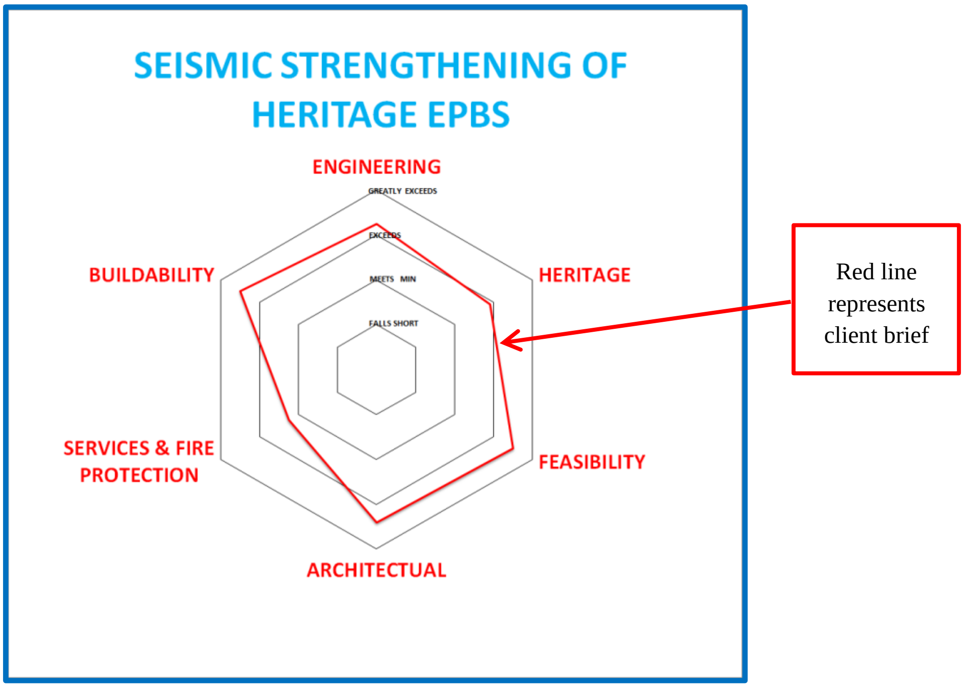

Figure 3

4.2.2 *Step Two: Assessment of Concept Designs*

Equipped with the client brief the design team would then develop a number of concept designs for the strengthening work. Client importance levels for each defined sub-criteria are ranked in one of three tiers (low, medium or high), which correlate to the tiered ranking for implied design performance (achieves minimum, exceeds or greatly exceeds). For instance if a client placed a low priority on a certain category then the design team will aim to simply meet minimum standards in relation to legal requirements or industry practice. If the client places a high priority on a category then the design team would aim to greatly exceed minimum requirements. The framework uses various shades of blue in the drop down selection options to visually highlight this correlation. Figure 4 illustrates the drop down box selections and correlation of rankings for the heritage assessment category, and Figure 5 displays the summary table for a completed assessment. The design assessment also has an additional option of 'falls short' where the design fails to meet minimum requirements. The correlative ranking system provides a starting point for the design team to understand design priorities and produce viable concepts at an early stage.

HERITAGE	**Building use:** Intervention maintain, enhance or discover new use for the building	**Significant Heritage fabric retention**	**Significant Heritage ambience retention**	**Interventions Reversible/ Removable**	**Positioning of Intervention: High vs low heritage value areas**	**Intervention Complimentary to Heritage:** Hidden/ Discrete OR Visible/ Transparent where appropriate	**Respect for contents & surroundings**	**Surface heights and levels retained**	**Retention of Heritage views & sightlines**	**Restorative Strengthening:** Repairs, maintenance or reinstatement of significant heritage items
DESIGN PERFORMANCE	GREATLY EXCEEDS	EXCEEDS	ACHIEVES MIN	GREATLY EXCEEDS	GREATLY EXCEEDS	EXCEEDS	EXCEEDS	EXCEEDS	GREATLY EXCEEDS	ACHIEVES MIN
CLIENT IMPORTANCE LEVEL	HIGH	MEDIUM	LOW	HIGH	MEDIUM	MEDIUM	LOW	GREATLY EXCEEDS EXCEEDS ACHIEVES MIN FALLS SHORT	HIGH	LOW

Figure 4

SUMMARY	SEISMIC ENGINEERING	HERITAGE	FEASIBILITY	ARCHITECTUAL	SERVICES & FIRE PROTECTION	BUILDABILITY
DESIGN PERFORMANCE	EXCEEDS	GREATLY EXCEEDS	EXCEEDS	EXCEEDS	GREATLY EXCEEDS	EXCEEDS
CLIENT IMPORTANCE LEVEL	HIGH	MEDIUM	HIGH	MEDIUM	LOW	HIGH

Figure 5

4.2.3 *Step Three: Select Preferred Design and Develop Construction Drawings.*

Figure 6 shows the completed spider graph that would be presented back to the client for each assessed concept design. The red client brief line portrays the priority level that the client places on each assessment category. Low, medium and high rankings correlate to design performance levels; meets minimum, exceeds and greatly exceeds respectively. The green highlighted area displays a strengthening design's overall performance as assessed by the design team. By comparing spider graphs each concept design can be compared and discussed, with a particular design ultimately selected for further development to construction drawings. It is important to emphasise that the framework is a subjective tool to help facilitate successful designs via a dynamic collaborative process. It is not intended that the framework provides a black and white answer as to which concept is the best. As one research participant noted *"I guess we find consultants rely on tools too much to drive the process. Whereas it's the team that should drive the process, not the tools. So [the framework] should never get in the way of open dynamic dialogue".*

Once a concept design is selected for further development the framework would be used as a tracking tool. As a selected design is progressed through each design stage it would be reassessed and the results reported back to the client. It is intended that the main spider graph be presented in a project control group or design team meeting with the assessment table presented as supplementary information. Figure 6 also illustrates the possible mismatches between the client brief and design performance in each assessment category. This would help stimulate discussions amongst the team as to the reasons behind the mismatches and whether the client's priorities or the design performance needs to change. The client will likely be more accepting of mismatches in some categories over others. Overall, the framework encourages a helpful collaborative dialogue among project team members. It is hoped that by the time construction drawings are completed the red outline of the client brief and design performance's green area would align.

4.2.4 *Step Four: Post-construction Review*

On completion the project team and client would meet to review how well design performance and client priorities aligned. The project will also likely have highlighted areas of improvement for the framework itself. A post-construction summary would also help to provide a benchmark for future assessments.

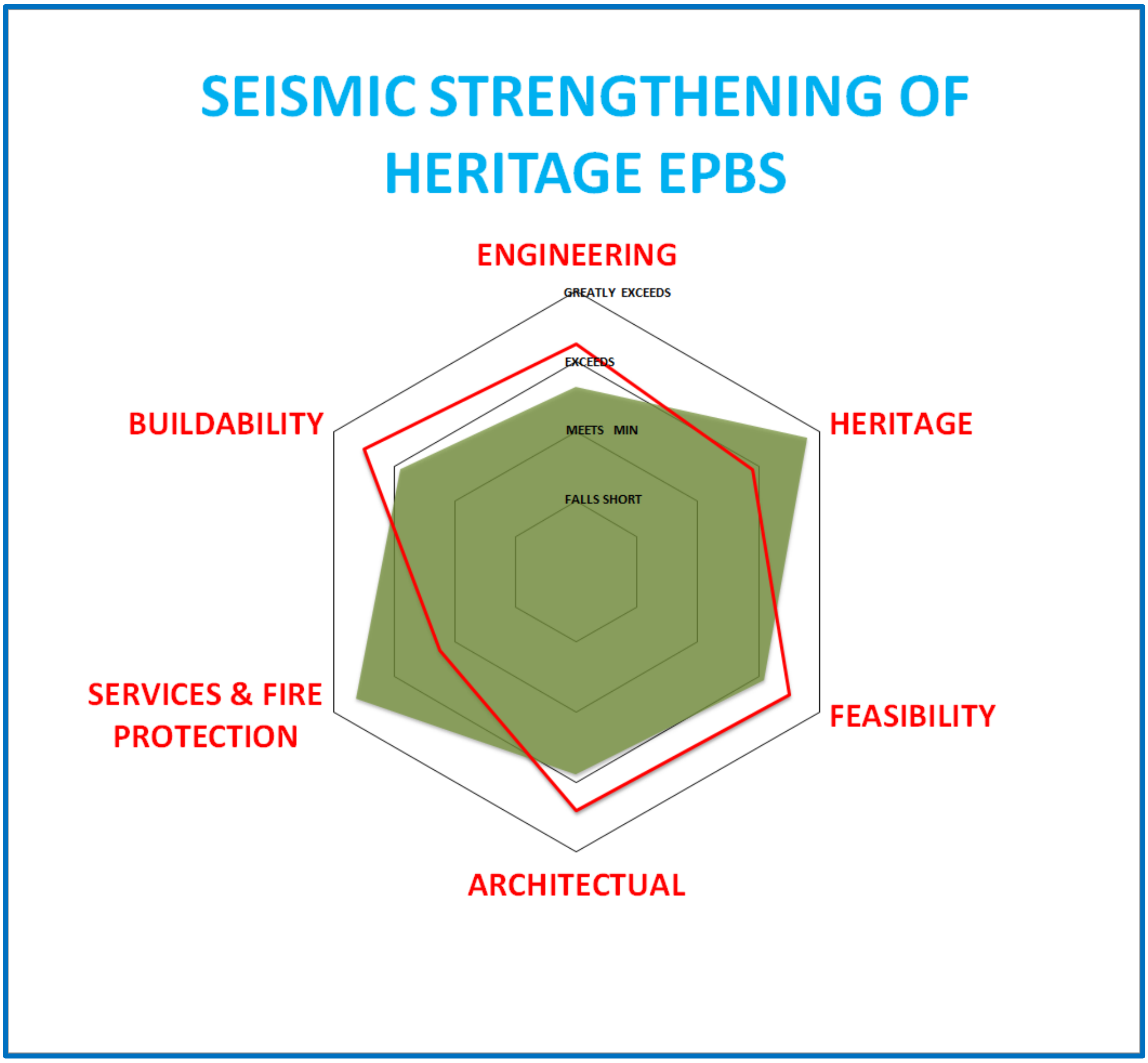

Figure 6

4.3 Industry Feedback

It was the researcher's intention that the framework remained a practical and industry relevant tool. Industry feedback from research participants is included below:

"I think it's a good tool…it's a simple visual for the client… it would steer the design team into keeping the alignment of what the clients original expectations were" – Construction Manager

"I think it's pretty good actually, it makes quite a lot of sense… I think having this as a check list when we are talking to [an engineer] or looking at an acquisition, or knowing we have to do some construction, clicking through this thing would be good, all the time…" – Heritage Building owner

"I think it's really excellent as a way of discussing things. A lot happens informally here, so we cover all this but you may occasionally miss things… I think it would be a good tool to slightly formalize the usual informal processes that happen… I think it's really good and really useful". – Commercial Property Developer

"This main graph is something you could bring into a meeting, and it explains a situation, where things are at. It's a really simple clear picture." – Construction Manager

"It's a good tracking tool of how the design team is performing." – Construction Manager

5 IMPLICATIONS & RECOMMENDATIONS

5.1 Implications

This research fills a gap in current studies by providing a comprehensive multidisciplinary assessment framework for heritage strengthening designs. Industry professionals & heritage building owners in New Zealand involved in seismic strengthening works will benefit from the use of the framework in a number of ways. First, the framework developed in this study helps provide a common language between professionals whilst being simple enough for key stakeholders with limited technical knowledge. Second, the developed framework is a conceptualisation of industry knowledge and experience that equips other professionals in the construction industry; several research participants commented that the framework formalised the thought processes already undertaken by experienced professionals. Third, the framework encourages and facilitates early collaboration whilst still allowing dynamic dialogue and decision making within the project team.

5.2 Limitations

While the framework has been progressively refined throughout the research process it has yet to be applied on a real life project. This will no doubt highlight areas for improvement and refinement, as well as additional assessment criteria. Another limitation is that all sub-assessment criteria rankings are equally weighted. In reality, some sub assessment criteria would be much more significant than others.

5.3 Future research

A number of future research opportunities exist to improve this current framework. These include but are not limited to;

- Industry testing of the assessment framework on real life projects
- Incorporating quantitative weightings to various principles and categories
- Exploring ways in which mismatches between client priorities and design performance are handled and displayed
- Producing templates of different project types
- Development of an app that automatically produces a design report
- Exploring the framework's use for any multidisciplinary design process outside of a heritage strengthening context.

6 CONCLUSION

This study addressed a gap in existing research by developing a multidisciplinary assessment framework for evaluating the effectiveness of heritage strengthening designs. The developed framework uses qualitative inputs that produce a table and spider graph presentation of the design's effectiveness. Original features of this study include a multidisciplinary framework that facilitates early collaboration throughout the design stage, measures 'design performance' in relationship to 'client priorities', provides new assessment principles gleaned from industry knowledge, and provides a tracking tool as a design progresses through each developmental stage. It is hoped that the assessment tool, with its multidisciplinary nature, will promote successful heritage strengthening designs through early and effective collaboration.

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