Hulathdoowage, N.D. and Chandanie, H., 2023. Comparative cost assessment of drywall technologies in disaster-induced housing reconstruction. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 332-343. DOI: https://doi.org/10.31705/WCS.2023.28. Available from: https://ciobwcs.com/papers/

COMPARATIVE COST ASSESSMENT OF DRYWALL TECHNOLOGIES IN DISASTER-INDUCED HOUSING RECONSTRUCTION

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ABSTRACT

The stagnant process of disaster-induced housing reconstruction (DHR) in Sri Lanka (SL) and the reluctance of victims and donors to use expensive technologies for DHR even if disaster-resilient, led to this research. Thus, the research aimed at conducting a comparative cost analysis of different drywall technologies in DHR as alternatives for fulfilling the growing demand for DHR; in doing so, this paper contextualised a mixed research design comprehending a twofold empirical study, which includes a preliminary-expert-interview survey and a questionnaire survey. Content analysis and statistical tools assisted the data analysis. Research outcomes revealed that labour cost-effectiveness, material availability, and sufficiency of unskilled labour are the most influential cost parameters. All ten drywall technologies are effective in terms of the initial cost and can further be tested to choose the best technology for a DHR. Novel aspects of this research are (i) evaluating various cost elements of different drywall technologies for DHR in Sri Lanka, and (ii) presenting research outcomes in a scorecard and a tiered list of drywall technologies, which facilitate choosing economically efficient drywall technologies to accelerate DHR. The scorecard is not restricted to DHR but it is widely practicable for other applications in SL.

Keywords: *Cost; Disaster; Dry Wall Technology; Gypsum Board; MDF Board; Sri Lanka.*

1. INTRODUCTION

Natural catastrophes have affected more than 2.9 billion people globally since 1980, wherein Disaster-induced Housing Reconstruction (DHR) has become a controversial responsibility worldwide (Atmaca & Atmaca, 2016). DHR is a collaborative attempt to deliver houses for victims/families at risk because of long-term natural forces, driven by anthropogenic pressures and natural transformation.

The government/ NGOs finance DHR in most developing countries either as a loan/donation (Lam & Kuipers, 2019). The obligation of paying back the credit-based-funds (Dikmen, 2005); social cost, burden on the public finance from government funding (Dikmen, 2010); and substantial economic loss of disasters exacerbate the financial crisis of the economies in developing countries (De Silva et al., 2021; Froude & Petley, 2018).

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Moreover, both donors and victims are typically reluctant to employ more expensive, as well as unaffordable technologies even if such technologies are disaster-resilient (Kijewski-Correa & Taflanidis, 2012). For example, DHR, after the 2004 tsunami in Sri Lanka (SL), did not adopt tsunami-resilient house designs due to their unaffordability (Batteate, 2006). This leads to evaluating any technology's economic viability before recommending to DHR. Still, the initial cost makes a heavy contribution because the capital cost of DHR is a collective commitment of communities, the government, and NGOs in most developing countries (Froude & Petley, 2018; Batteate, 2006).

On the other hand, victims should be informed of a spectrum of alternative construction materials to avoid causing material shortages during DHR, and to tackle the growing pressure of DHR (Kennedy et al., 2008). Simultaneously, Suarez et al. (2008) specified that DHR continuously focuses on developing appropriate material solutions, so Hulathdoowage et al., (2021) assessed the time-based performance of drywall technologies. Although drywall is not a widespread practice in DHR in the developing context (Hulathdoowage & Hadiwattage, 2021), developed countries have exploited its most significant advantage (Sabau et al., 2018). For example, Barrios et al. (2020) proved that most housing units sustained from Hurricane Harvey (Texas, USA) in 2017, were featured drywall piles. The scientifically-verified positive characteristics of drywall technologies include 5-8 times quicker installation process, less labour requirement, structural cost-saving (Tamboli et al., 2018), decreased cooling demand, and less environmental impact (Mandilaras et al., 2013). Arab et al., (2021) proved that drywall compared to brick wall decreases natural gas consumption by 66.93%, electricity demand by 42.59%, and carbon emissions by 22.54%, and these percentages would be higher in coming years.

Moreover, Khodahemmati and Shahandashti (2020) evaluated construction material cost fluctuation over six years centred on Hurricane Katrina in New Orleans, Louisiana and confirmed that the poor consideration of the capital cost of construction materials leads to budget shortages of DHR. Budget shortages increase the period in temporary huts/ tents for victims. Thus, concerning the benefits of drywall, researchers examined the Research Question (RQ) below:

> *RQ: What are the influential cost elements, and the comparatively efficient drywall technologies in terms of capital cost for DHR?*

A trivial number of scholarly articles are available on the subject. Hulathdoowage and Hadiwattage (2021) established the applicability of drywall for DHR based on a case-study-based analysis. Hulathdoowage et al. (2021) evaluated the time performance of different drywall technologies for DHR. Munasinghe (2018) established the suitability of EPS wall panels for SL concerning thermal comfort. Shamloo et al. (2021) evaluated the effects of four structural systems including drywalls (wood and EPS) on DHR and confirmed that each system fulfils part of DHR needs, e.g. cost and time performance, environmental considerations, and land use. But none of them answers the above RQ. The remaining content of the paper is structured as follows; literature review elaborating on the applicability of drywall technologies for DHR in SL; research methodology; results and discussion regarding a cost comparison of ten drywalls; conclusions of critical findings.

2. LITERATURE REVIEW

This section discusses the applicability of drywall for the host country, SL. However, brick and block walls are still common to SL. Hence, Hulathdoowage and Hadiwattage (2021) compared the performance between block wall and drywall technologies. Similarly, Indian constructions employ brick walls, but new construction techniques are currently emerging, e.g., ferro-cement and gypsum wall panels (Patil et al., 2022).

2.1 NEXUS BETWEEN FINANCIAL BACKGROUND OF DISASTER RELOCATION AND DRYWALL CONSTRUCTION IN SRI LANKA

In 2020, the number of families, which needed to rehabilitate due to the high risk of landslides in SL, was 2,963, and 847 victims were residing in temporary shelters due to flooding and 567 due to landslides expecting permanent residents (Ministry of Disaster Management, 2021). Lethargic characteristics are apparent in most DHR projects in SL, i.e., Hulathdoowage and Hadiwattage (2021) have witnessed victims in tents even after three years of the 2016 Aranayake landslide in SL, which critically obstructs the livelihood of the victims. As per Quarantelli et al. (1995), temporary shelters have already become temporary houses, and there is no sign of permanent houses. Tents arranged for temporary sheltering never fulfil even the very basic needs, irrespective of disaster resilience. Therefore, especially in developing countries, acknowledging quick and affordable construction techniques has more value than in developed countries.

From 1998 to 2012, flooding made the highest cost contribution per year, which was LKR 32 billion and next, and cyclones produced LKR 11 billion costs (Ministry of Disaster Management, 2015). The regular fluvial flooding can transfer tens of thousands of Sri Lankans into transitory poverty, deterring the progress of the country on shared responsibility and poverty eradication (Walsh & Hallegatte, 2019).

ADB (2019) manifested the financial background of DHR in SL in a red zone, further identifying limited financial arrangements, the absence of a national disaster fund, unavailable financing plans, and ineffective insurance strategies. Most of the livelihood opportunities get abandoned for a long-time after a natural catastrophe, such as the lower capacity to carry out fishing due to fragile settings in the community networks in resettlement camps, destroyed crops and lands in agriculture, the need for colossal funding to relocate businesses, difficulties of reinstating tourism (Finucane et al., 2020).

As a critical element, wall construction occupied more than 10% of the total budget of a typical single-house produced after the 2016 Aranayake landslide in SL (Hulathdoowage & Hadiwattage, 2021). Moreover, wall materials are subjected to inflation during the recovery phase (Ghannad et al., 2019; Harris, 2005). Thus, drywall could be a promising solution to fix this matter to some extent because of its cheaper and faster process, and by increasing the number of alternative technologies (Tamboli et al., 2018).

The labour wage rate also rises due to inflation at the recovery phase, i.e., skilled labour rate became almost treble after the tsunami, and finding skilled labours, such as masons, makes the process more difficult (Ghannad et al., 2019; Harris, 2005). Moreover, there is a continuous labour shortage in the Sri Lankan construction sector, especially skilled labours (Pathiraja, 2008; Pathirana, 2021), wherein the labour shortage was 400,000 workers in 2017 (Jayasinghe, 2020). Ghannad et al., (2019) further estimated the capability of modular construction technologies to solve labour-related issues as it ensures higher productivity, lower labour requirement, enhanced safety of construction, quick response to DHR, lower site congestion. Drywall is also a modular technology and provides the same advantages because it demands only on-site assembly.

When choosing materials for DHR, out of the box thinking pattern is more effective to secure cost-effectiveness (Bruen et al., 2021). Hulathdoowage and Hadiwattage (2021) evaluated two case studies induced by 2016 Aranayake GHR and forecasted that three other houses could have been constructed in each case study by replacing block walls with drywall panels (e.g., gypsum board).

2.2 ACCESSIBLE DRYWALL TECHNOLOGIES IN SRI LANKA

Referring to secondary data (Hulathdoowage et al., 2021), the set of ten drywall technologies were adopted for the empirical study concerning the availability for a mass construction such as DHR in SL, encompassing Gypsum board partitions, Cement bonded particleboard (Danane & Wagh, 2018), Expanded Polystyrene Sandwich (EPS) panels (Munasinghe, 2018), Glass fibre reinforced gypsum panel (Bardhan and Debnath, 2018), Cellulose fibre cement composite panels (Ardanuy & Claramunt, 2015), Medium Density Fibber (MDF) board, Paddy straw composite board (DURRA) (Athambawa et al., 2014), Autoclaved Lightweight Concrete (ALC) board, Oriented Standard Board (OSB)-composite material (Chen, 2018), Calcium silicate wall panel board (Si, 2018). Literature sources (Athambawa et al., 2014; Chang et al., 2010) also confirm evaluating local materials to achieve optimum economic viability.

3. RESEARCH METHODOLOGY

Due to the similar nature of both studies, we adopted the methodology followed by Hulathdoowage et al., (2021), who evaluated the time efficacy of drywall technologies.

3.1 DATA COLLECTION

Initially, a series of preliminary interviews with three professionals was conducted to derive a comprehensive set of cost parameters required to assess the initial economic viability of wall construction in DHR and to structure the questionnaire survey. Next, we carried out a questionnaire survey (inclusive of 48 professionals within the sample) for ranking a set of chosen drywall technologies against each cost parameter.

By evaluating the comparative cost performance of different drywall technologies quantitatively with a large sample such as 48, we could avoid the inaccuracies of having a case-dependent comparison and alleviate partial responses to overcome the weaknesses of the previous case study-based studies (Atmaca & Atmaca, 2016). The principal researcher personally visited most of the experts and explained whenever they queried to secure the accuracy of the responses. Responses were weighted based on the experience range of experts to reduce the impact of biased responses.

3.2 DATA ANALYSIS

We analysed interview transcripts subjected to manual content analysis, and questionnaire responses aided on SPSS 20 software package and Microsoft Excel software. Mean Weighted Rating (MWR), skewness, and standard deviation, were the main statistical tools used for the quantitative analysis. Skewness presented the normality of the data distribution. Standard deviation presented the reliability of the data set.

The sample consisted of four groups of experts, i.e. (i) Drywall (20.83%), (ii) DHR (25.00%), (iii) Both (8.33%), and (iii) construction professionals (45.83%). Experts who were having more than 5 years of experience in the respective fields accounted for the first three categories, and the last category was purposefully selected to include professionals who are having some exposure (<5 years) to both drywall technologies and DHR. Moreover, we collected perception-based responses because experts ranked the drywall technologies under each cost parameter. To reduce the biases, responses were weighted based on the experience level, and Gunasena (2010) was followed to justify the weighting decisions.

Subsequently, Equation 1 was utilised to assign scores to the questionnaire responses. The set of ten drywall technologies was assigned MWR as scores and graded under each initial cost parameter of wall construction to develop a scorecard.

$$MWR = \frac{\sum_{i=0}^{N}(W_i \times F_i)}{N} \quad (01)$$

Where, MWR - Mean Weighted Rating for an attribute, W_i - Constant giving to weight each case, F_i - Frequency of responses, N - Number of responses (Hulathdoowage et al., 2021).

Table 1 establishes five levels to interpret MWR values and defines a colour code to improve the visual clarity of data.

Table 1: MWR values interpretation (Gunasena, 2010)

MWR value	Interpretation	Colour code
4-5	Strongly higher feasibility	
3-4	Higher feasibility	
2-3	Average feasibility	
1-2	Lower feasibility	
0-1	Strongly lower feasibility	

Equation 2 was applied to calculate the overall score of each drywall technology representing its comparative economic viability based on initial cost parameters (C1, C2, C3,……., Cx). Equation 2 was derived from Equation 1, wherein the final number of cost parameters (x) was determined from the preliminary-expert-interview survey as six.

$$Overall\ Score = \frac{\sum_{i=0}^{N}\left[\sum_{x=1}^{6}\left(MWR_{C_xDT_i} \times MWR_{C_x}\right)\right] \times 100\%}{\sum_{x=1}^{6} MWR_{C_X} \times K} \quad (02)$$

Where, MWR_{CxDTi}: Mean Weighted Rating of each drywall technology under Cx, MWR_{Cx}: Mean Weighted Rating of Cx, x: Cost parameters, K: The maximum overall score of each technology.

4. PRELIMINARY-EXPERT-INTERVIEW SURVEY RESULTS

We engaged in preliminary interviews to verify the initial cost parameters identified from literature, and to fine-tune the questionnaire. Three professionals having more than 10 years of experience in their respective field (2 – DHR and 1 - drywall) were interviewed. During the interviews, initial cost parameters identified from the literature were thoroughly examined against the characteristics of the recovery phase to derive a description for each parameter (refer to Table 2).

Table 2: Cost parameters along with descriptions

Initial cost parameter	Description	References
Labour cost-effectiveness	The capacity of having a minimum total cost associated with both skilled and unskilled labour components	(Basnayake, 2018; IPS, 2006; Martínez et al., 2020)
Sufficiency of unskilled labour	Capability to fulfil the labour requirement with unskilled labours	(IPS, 2006; Martínez et al., 2020; Zea Escamilla & Habert, 2015)
Material availability	Effectiveness of the supply chain to cater for the material demand for a mass construction	(Hulathdoowage & Hadiwattege, 2021; Zea Escamilla & Habert, 2015)
Material cost-effectiveness	The capacity of having a minimum retail price for materials	(IPS, 2006; Dikmen, 2010)
Transportation cost-effectiveness	The capacity of having a minimum transportation cost via logistical easiness of materials	(Demirli et al., 2015)
Minimum wastage rate	The capacity of having a minimum additional cost due to material wastage at the site	(Bardhan & Debnath, 2018)

5. QUESTIONNAIRE SURVEY RESULTS

The second round of the empirical study was an expert questionnaire survey, wherein the respondents were specialised in a subject area (Kachroo & Kachen, 2018).

5.1 DEVELOPING THE SCORECARD

Respondents ranked the six cost parameters aided on a 1-5 Likert scale to investigate the priority level for DHR and then ranked the list of ten drywall technologies under each cost parameter (C1, C2,..., C6) referring to the same 1-5 Likert scale. Concisely, we agglomerated those two rankings into a scorecard, which is illustrative in Figure 1.

5.1.1 Prioritising Cost Parameters of Wall Construction in DHR

Figure 1 demonstrates that the priority of the first five cost parameters is strongly higher, whilst the last one falls within the "higher range" (refer to Table 1). Labour cost-effectiveness, material availability, and sufficiency of unskilled labour are the most influential cost parameters. To verify, labour shortage, skilled labour unavailability, increments of the labour wages at the recovery stage, and material shortage are frequent issues in DHR projects in SL, further causing delays and disruptions (Ghannad et al., 2019; Harris, 2005; Pathiraja, 2008; Pathirana, 2021). Material cost-effectiveness and transportation cost-effectiveness come next in the order standing within the "strongly higher range", whereas minimum wastage rate is the lowest.

5.1.2 Prioritising Drywall Technologies Against Each Cost Parameter of Wall Construction in DHR

Figure 1 further distinguishes the effectiveness of different drywall technologies wherein the most feasible drywall technologies under the parameter "Labour cost-effectiveness" are Gypsum Board and Calcium Silicate Panel. Easiness of installing and less labour requirement for assembling gypsum boards diminish the labour cost (Tamboli et al., 2018). Regarding labour cost-effectiveness, EPC panel has assigned to "Higher range" and for sufficiency of unskilled labour, to "Strongly higher range". In fact, EPS panel partitioning utilizes less time, e.g., one and half days of unskilled labour to assemble a 130 sqft room (Munasinghe, 2018). Sequentially, the most available technologies in SL for a considerable demand are MDF panel, gypsum board, and DURRA board. Being scored by 3.4, gypsum board has a minimum wastage rate, which is 5% of the total material required (Condeixa et al., 2015).

5.2 OVERALL INITIAL COST PERFORMANCE OF TEN DRYWALL TECHNOLOGIES IN DHR

The set of ten drywall technologies shown in Figure 1 was manifested in a chart, assigning overall score values (refer Equation 2), illustrating the overall cost-performance of drywall technologies for DHR (refer Figure 2).

Pertaining to Figure 2, two ends represent gypsum board panels (highest performance) and ALC panels (lowest performance). Similar results on the economic performance of gypsum board panels have been assured by Danane and Wagh (2018) related to the Indian construction sector. Overall, all ten technologies have shown more than 50% of the maximum performance.

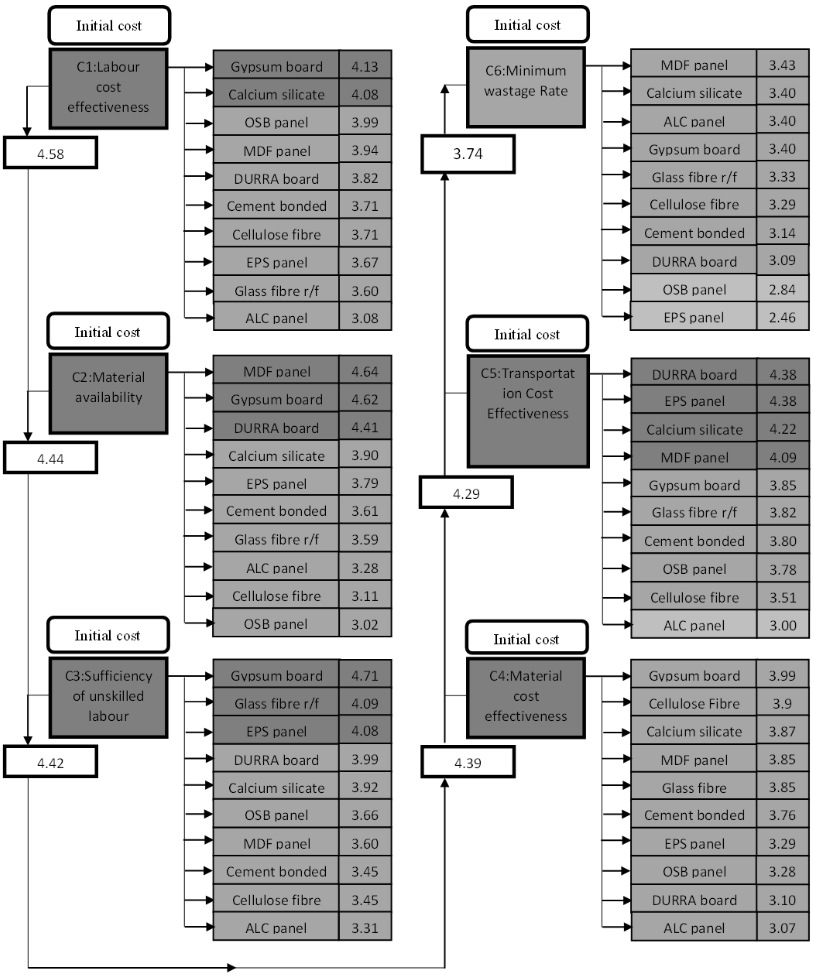

Figure 1: Scorecard regarding the cost performance of drywall technologies in DHR

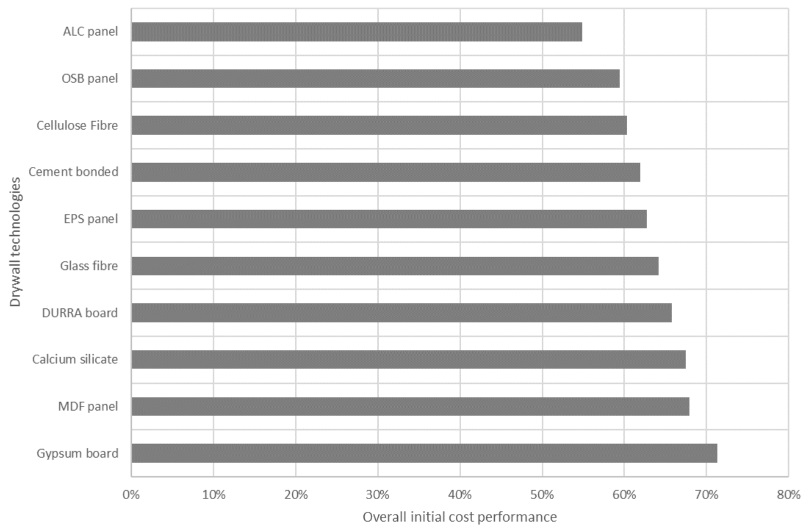

Figure 2: Tiered list of ten drywall technologies in DHR

6. VALIDATION PROCESS OF RESEARCH FINDINGS

Due to the limited number of scholarly articles available on the subject matter, the scorecard (Figure 1) and the tiered drywall list (Figure 2) were presented to two experts of DHR and drywall technologies, respectively holding more than ten years of experience in their relevant field for externally validating the outcomes of the research. Therefore, both Figure 1 and Figure 2 are applicable for DHR in developing countries, struggling with similar difficulties.

Subsequently, prices of drywall panels and material prices for masonry walls were collected from two wholesale companies to further validate the outcomes of the expert questionnaire survey (material cost-effectiveness) (refer to Table 3).

Table 3: Retail prices of 8'×4' sized wall panels in Sri Lanka in 2022

Drywall technology	Price (LKR)	Thickness (mm)
Masonry wall technologies		
Brick wall	5,692.00	112.5
Block wall	4,732.80	100
Drywall technologies		
Gypsum board	932.00	15
Cellulose Fibre	1,012.00	15
Calcium silicate	1,078.00	22
Glass fibre	1,507.00	15
MDF	2,026.00	12
Cement bonded	2,087.00	18
EPS	2,229.00	75
OSB	2,330.00	25
DURRA	3,920.00	58
ALC	4,559.00	75

Since DHR creates a massive demand for wall materials, prices collected were applicable for purchasing more than 1000 panels. The drywall technologies are more efficient in terms of material cost than masonry wall technologies (112.5 mm thick brick wall and 100mm thick block wall) except ALC panel, which is almost similar to the block wall. However, ALC panels would be even more cost-efficient than block walls when increasing the labour rate during the recovery phase due to inflation (Ghannad et al., 2019; Harris, 2005).

7. APPLICATION OF RESEARCH FINDINGS

The scorecard (Figure 1) and the tiered list of drywall technologies (Figure 2) are particularly applicable for SL but can be applied for similar developing countries by reiterating the same methodology. Rankings of drywall technologies under each cost parameter are not restricted to the disaster context, i.e., material availability for a bulk supply is also a significant analysis for any application of drywall technologies in SL, such as high-rise buildings, commercial buildings. Moreover, the tiered list of drywall technologies is a significant indication to choose the best technology on the initial cost out of several potential technologies.

Concerning Figure 1, Figure 2, and Table 3, all ten drywall technologies are efficient concerning the initial cost, and therefore, this research recommends all ten drywall technologies as alternatives to masonry wall construction in case of fulfilling mass demands of housing construction, such as DHR. Despite this, other factors, such as disaster-resilient requirements should be evaluated to choose the best technology.

To strengthen research in the same direction, further research areas were identified under the guidance of the two experts during the validation process. The same research methodology can be extended to develop a similar set of parameters on the maintenance cost of drywall technologies, finally, comprehending into a scorecard. The applicability of drywall technologies for the interior and exterior should be differentiated when evaluating the resilience against extreme weather conditions. On the other hand, numerous drywall technologies show distinctive levels of resilience under different disaster conditions and the expected resilience level depends on the disaster exposure in the region, so that both factors need to be evaluated in future research. Moreover, Hulathdoowage and Hadiwattege (2021) have explained the future research directions required to implement drywall technologies in detail.

8. CONCLUSIONS AND RECOMMENDATIONS

Capital cost-effectiveness is prominent in DHR due to many funding constraints in developing countries, such as difficulties of paying back the credit-based funds, incapacity of the government, failure to withstand the enormous economic loss of disasters, unfamiliar and expensive insurance programs, and inflation during the recovery period. For counteracting such bottlenecks and as an alternative wall technology to tackle the growing pressure of DHR, this study investigated the comparative cost performance of drywalls in DHR, strengthening the research direction shown by Hulathdoowage and Hadiwattege (2021).

Six cost parameters were empirically assessed, out of which five parameters were positioned in the "strongly higher" range. Labour cost-effectiveness, material availability, and sufficiency of unskilled labour became top influential parameters, further realising the literature on the critical nature of the labour component. Finally, we developed a scorecard that demonstrates a tiered list of ten drywall technologies under each cost parameter. This scorecard facilitates choosing a suitable drywall for wall construction in DHR. The significance of cost parameters has evaluated specifically for DHR. Still, the ranking of drywall technologies under each cost performance would be applicable for other applications as well, e.g., commercial buildings.

This research recommends all ten drywall technologies as alternatives to conventional masonry wall technologies for DHR concerning the overall initial cost performance. Therefore, Figure 1 and Figure 2 can be adapted for the policy development procedure of DHR in SL, such as preparing rehabilitation guidelines, improving the community awareness process of drywall technologies, and conducting further research and development on adopting drywall technologies in DHR.

9. ACKNOWLEDGEMENTS

The authors would like to express their gratitude to all the interviewees and questionnaire survey respondents.

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