Incorparation of Disasater Risk Reduction and Disasater Resilient Mechanisms into the Building Tool of GREENSL® Rating System for Built Environment

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Abstract Disaster risk in Sri Lanka has been increasing mainly due to rapid unplanned commercialization and development of cities, infrastructure with poor quality, and the impacts of climate change which has exposed the built environment severely to natural hazards. Out of all the hazards, floods, landslides, heavy winds and tsunamis have caused the highest number of damages to buildings and loss of human lives during the period of 1965–2019. Although the Green Building Council of Sri Lanka (GBCSL) has initiated many resilient measures in energy and resources usage in buildings, it has not specifically identified the requirement of integrating Disaster Risk Reduction (DRR) mechanisms into their green rating tools. This research study is focused on identifying structural and non-structural DRR measures for the three disasters; floods, landslides and high winds, developing guidelines and finally proposing a new disaster resilient building tool under the main eight categories of the existing building tool for GREENSL® Rating System for Built Environment V2.0 with expert committee inputs; followed by eleven surveys carried out in green certified buildings situated in flood, landslide and high wind prone areas and less or no hazard prone areas for validation. It is highly recommended to use new disaster resilient building tool in certifying buildings situated in flood and landslide prone areas, moderately recommended to use in high wind areas and finally it is acceptable to use the existing building tool for GREENSL® Rating System for Built Environment V2.0 for the buildings situated in less or no hazard prone areas. However, it can be advised to use the new disaster resilient building tool even for the buildings situated in less or no hazard prone areas as it addresses the general DRR measures to combat adverse climatic trends in future.

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R. Dissanayake et al. (eds.), *ICSBE 2020*, Lecture Notes in Civil Engineering 174,
https://doi.org/10.1007/978-981-16-4412-2_20

Keywords Natural hazards · Disaster risk reduction · Green rating systems · Green buildings · Disaster resilient building

1 Introduction

Catastrophic disasters induced by natural and man-made hazards are inevitable, but prevention measures will help to reduce the social, environmental and economical adverse impacts immensely. World Health Organization declares that globally, the number of people killed by natural disasters exceeds 90,000 and nearly 160 million people are affected annually. Natural disasters such as floods, droughts, earthquakes, tsunamis, landslides, hurricanes, volcanic eruptions, wildfires, and heat waves not only cause immediate destructions to the physical, biological and social environment, but also impose a long-term threat on the health and well-being of its people [1]. Also, the report 'Economic losses, Poverty and Disaster—1998 and 2017' highlights that geophysical and climate-related disasters have killed around 1.3 million people and made another 4.4 billion people injured, disabled, displaced or in need of assistance during the period of 1998 and 2017. During 1998–2017, the countries hit by natural disasters have gone through direct economic losses valued at US$ 2,908 billion [2]. The Munich Re NatCatSERVICE, reports about 850 natural hazard induced disasters occurred in 2018 only. Out of them, 5% was reported to be Geophysical disasters such as earthquakes, volcanic eruptions and tsunamis, 42%, to be storms, 46% to be floods, flash floods and landslides and 7% to be wildfire, cold and heat. 43% of all the disasters have been reported from Asia, 20% from North America, 14% from Europe, 13% from Africa and 10% from other regions [3].

As Sri Lanka is a tropical country, it often meets with frequent rainfalls and increased temperatures throughout the year. Sri Lanka's climate is governed by the Southwest and Northeast monsoons and two inter monsoon seasons. Behavioral patterns of the Bay of Bengal widely affect the changes in wind patterns and changes in durations of occurrence [4]. Majority of Sri Lankan natural hazards are identified to be hydro-meteorological hazards like floods, high winds, landslides, etc. of which floods are most critical. River floods, urban and flash floods, landslides, cyclones, wildfires are considered to be the main hazards with high risk and coastal erosion, tsunami and droughts are considered to be of medium risk [5]. Out of all, floods and landslides are the most common natural hazards effective for Sri Lanka. Cyclones, droughts, and tsunamis are considered to be severe hazards though their occurrences are of less frequency [5]. Since 1965, 224,760 houses have been damaged due to floods while 128,705 houses have been affected severely from high winds, 105,293 houses have been damaged due to tsunami and 14,761 houses from landslides [6]. Economic losses caused due to natural disasters, accounts for an average annual loss of $380 million which is averagely 3% of total government expenditure, according to World Bank estimates. As a distribution 33.3% accounts for Tsunamis, 30.8% for floods, 29.6% for cyclones and heavy winds and 6.3% due to other hazards during the period of 1990 to 2014 in Sri Lanka [5].

Skyrocketing catastrophic losses and destructions imposed by natural hazards are mainly due to rapid rate of urban growth, unplanned urbanization, poor quality buildings and infrastructure, and the adverse impacts of climate change [7]. A study carried out by the AIT in 2012 has examined on integrating of DRR measures into the national building codes of Sri Lanka for wind, rain and flood and landslides [8]. It manifests that a comprehensive disaster resilient building code could not be found yet in Sri Lanka, which is an essential need to be met in transforming the existing construction industry into a sustainable one. There is an unfilled gap in the GREENSL® Rating System for Built Environment where it could incorporate disaster risk reduction mechanisms. Even a platinum rated green building constructed in a sustainable manner is still prone to damages from natural disasters if proper DRR measures have not been incorporated. As floods, landslides and heavy winds are the most frequent, highly vulnerable and which have caused significant building damages around the country, only the DRR measures related to above three hazards are considered in developing the disaster resilient green rating building tool. There are two types of DRR mechanisms for hazard preparation and mitigation namely structural (hard) and non-structural (soft) measures. Apart from the DRR and disaster resilient global and local frameworks, five green rating tools from four countries were selected based on the factors of, usage and popularity of the tools, vulnerability level of the counties for natural hazards and their world risk index. This research study aims in identifying structural and non-structural DRR mechanisms for floods, landslides and heavy winds aligned with the local and global frameworks for DRR and disaster resilience, developing a set of guidelines using the identified structural and non-structural DRR mechanisms and finally developing a new disaster resilient building tool through incorporating the developed DRR and disaster resilient guidelines into the GREENSL® Rating System for Built Environment.

2 Literature Review

2.1 Global Frameworks for Disaster Risk Reduction

In 2015 three international policy frameworks were established namely Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030 (March 2015), the Sustainable Development Goals (SDGs; September 2015) and the Climate Change Agreement (December 2015). Before the development and implementation of the SFDRR 2015–2030, Millennium Declaration (2000) and Hyogo Framework for Action (HFA; 2005–2015) were the frameworks used by the countries to manage and prepare for the natural hazards and the induced disaster risks.

As SFDRR was the latest and most updated international policy framework on DRR, it was considered in selecting guidelines required for the disaster resilient green building tool. The main aim of the SFDRR is to prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience [9]. Out of the seven global targets, target 3; Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030 and target 4; Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030 were considered in developing guidelines. Similarly, out of four priorities for action, priority 3; Investing in disaster risk reduction for resilience and out of the twelve guiding principles principle 3, 8 and 9 were considered in developing guidelines for green rating systems. SDGs are a collection of 17 global goals introduced by United Nations [10]. Targets under SDG 11; Sustainable cities and under SDG 9; Building resilient infrastructure have a strong interrelationship between DRR and sustainable development. Resilient Construction, sustainable and inclusive industrialization, innovative, resilient, safe and sustainable human settlements and cities are the main goals of the above two SDGs [11].

2.2 Green Building Councils and Green Rating Systems

A 'green' building is a building that, minimizes negative impacts, and make positive impacts, on the environment throughout its life cycle in planning, designing, constructing, or operating [12]. The World Green Building Council (WGBC) is a global leader comprised with nearly 80 green building councils around the world. Green Building Councils develop and lead many of world's green rating tools. Green building rating systems can be defined as a set of guidelines and criteria which a building or a structure is used to assess and recognize when certain green requirements or standards are met [12]. Out of 100 s of existing green rating tools, this literature review is narrowed down into few rating systems, namely, Leadership in Energy and Environmental Design (LEED) and ReLi of Green Building Council of United States, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) of Japanese Green Building Council, GREENSHIP of Green Building Council of Indonesia and Building for Ecologically Responsive Design Excellence (BERDE) of Green Building Council of Philippines for this research. Table 1 summarizes the existing DRR and disaster resilient mechanisms incorporated into the building tools of the above-mentioned green rating systems.

Due to the very high disaster risk profile of Philippines, international, local, government and private organizations have developed many guidelines and frameworks aligned with global frameworks. But the integration of these DRR and disaster resilient mechanisms into the construction industry and BERDE green rating tool is very minimal. The only consideration it has taken is that, during the predesign phase, it is determined whether Environmental Impact Assessment (EIA) and Engineering, Geological, and Geo-Hazard Assessment (EGGA) are needed to be conducted to

Table 1 Existing DRR and disaster resilient measures in different green rating tools

Green rating	Main category	Sub-category	Existing DRR measures available
LEED v4.1 for new construction and design rating tool [11]	Location and Transportation (LT)	Sensitive land protection	Flood hazard areas shown on a legally adopted flood hazard map or designated by local jurisdiction or the state
			Management of areas with wetlands
	Sustainable Sites (SS)	Construction activity pollution prevention	Reduce pollution from construction activities by controlling soil erosion, waterway sedimentation, and airborne dust
		Site assessment	Topography and Hydrography
RELi 2.0 Rating System [12]	Panoramic Approach (AP)	Short-term hazard preparedness + mitigation	Potential actions that can be to mitigate short-term hazards to the building and community occupants, physical property + infrastructure
		Long-term adaptability, diversity + redundancy	Restore the effects due to desertification, beach erosion, and loss of wetlands
			Implement plans to prepare for long-term climatic changes
	Hazard Preparedness (HP)	Emergency planning for hazards	Fundamental safety for occupants during disaster and emergency by developing an Emergency Preparedness Plan
		Fundamental access to: first aid, emergency supplies, water, food, communications	Fundamental safety for occupants during emergencies for at least 96-h with first aid kit and training

(continued)

Table 1 (continued)

Green rating	Main category	Sub-category	Existing DRR measures available
			Provide at least a telephone landline along a cell phone with text message capabilities and an emergency alert radio + walkie-talkies
		Emergency planning for common hazards + extreme events	Enhanced Emergency Planning for Common Hazards + Extreme Events using, communications, life safety, property protection and community outreach
			Expand FEMA Guide 141 Planning Considerations
		Enhanced Access: Emergency Care + Supplies, Water, Food, Communications	Provide safety for occupants during disasters and/or emergencies such as, first aid, short supply items, access to emergency care, sanitation, communication capacity + equipment, emergency back-up power and portable emergency lighting
		Community Education: Weather, Safety + Risks	Inform and educate the public and authorities about increasing weather, safety and resiliency risks
	Hazard Adaptation & Mitigation (HA)	Sites of Avoidance + Repair: 500-Year Floodplain, Storm Surge + Sea Rise	Avoid areas within 500-year floodplains
			Building on green field sites below the 500-year floodplain is not permitted
			Avoid coastal zones inundated by 2″-6″ of sea level rise, or provide a solution

(continued)

Table 1 (continued)

Green rating	Main category	Sub-category	Existing DRR measures available
		Emergency Operations: Back-up Power + Operations	Design for power outages from grid
			Provide back-up power, switching gear, power hook-ups and temporary generators to provide power for critical utilities
			Locate equipment and infrastructure above 500-year floodplain
			If equipment is not sufficiently elevated then apply dry flood protection techniques
		Transit + Transportation System Protection + Continuous Operations	Provide and Maintain Flood Protection + Energy Resiliency in transportation systems for short-term and long-term resiliency
	Energy, Water & Food (EW)	Plan for Rainwater Harvesting, Resilient Landscapes + Food Production	Plan a minimum of 50% of the roof area to capture water for reuse
			Plan structure and site for roof and/or ground level collection of rainwater for project
		Water Efficiency + Resilient Water + Landscapes	Provide on-site rainwater or recycled water storage to cover toilet flushing and mechanical for emergency operations for at least 96 h
CASBEE-UD Rating System [13]	Society	Security/Safety	Disaster Prevention: Use hazard maps and preparedness with communication, water & energy supply during an emergency

(continued)

Table 1 (continued)

Green rating	Main category	Sub-category	Existing DRR measures available
			Disaster Response: Formation of evacuation routes and sites/shelters and emergency operations for continuity of operations
GREENSHIP New Building Version 1.0 Rating Tool [14]	Appropriate Site Development (ASD)	Storm Water Management	Integrated rainwater management system which will reduce runoff volume into the city drainage network from building sites and reduce flooding
	Energy Efficiency & Conservation (EEC)	Climate Change Impact	To provide and increase the knowledge related to the effect of excessive energy consumption towards climate change

comply with the requirements in securing Environmental Compliance Certificate (ECC) [15].

2.3 GREENSL® Rating Systems for Built Environment

GBCSL is the pioneer in certifying the green buildings and infrastructures in Sri Lanka using their developed tools such that; GREENSL® Rating System for New Buildings, GREENSL® Rating System for Existing Buildings, GREENSL® Rating System for Cities, GREENSL® Rating System for Transportation Infrastructure and GREENSL® Rating System for Green Products [16]. The GREENSL® Rating System for New Buildings hich is the main focus of the literature survey consists of main 8 categories with prerequisites (mandatory requirements to fulfill without points) and credits (optional requirements to earn points). Eight categories are, Management (4 Points), Sustainable Sites (25 Points), Water Efficiency (14 Points), Energy and Atmosphere (22 Points), Materials and Resources (14 Points), Indoor Environmental Quality (13 Points), Innovation and Design Process (4 Points) and Social and Cultural Awareness (4 Points) [17]. Table 2 summarizes the current extent of integration of DRR measures in this tool.

Table 2 Existing DRR and disaster resilient measures in GREENSL® rating system for new buildings tool [17]

Main category	Sub-category	Existing DRR measures available
Sustainable Sites (SS)	Site selection	Land whose elevation is lower than 1.5 m above the elevation of the 50-year flood level
		Land which is prior to acquisition for the project was public parkland or land identified as landslide-prone areas
	Site assessment and development	Hydrology: Flood hazard areas, delineated wetlands, lakes, streams, shorelines, rainwater collection and reuse opportunities and initial water storage capacity on site

2.4 Disaster Risk Reduction (DRR) Mechanisms and Disaster Resilient Local Guidelines

This subsection is focused on the DRR mechanisms and disaster resilient local guidelines for floods, landslides and heavy winds which can be divided into two major aspects as; Structural (hard) DRR measures and Non-Structural (soft) DRR measures. Table 3 illustrates the structural and non-structural DRR and disaster resilient local guidelines and mechanism for floods, landslides and heavy winds.

3 Methodology

Research methodology used for this research study in developing a disaster resilient building tool of the GREENSL® Rating System is illustrated in Fig. 1 which consists of five major steps.

According to Fig. 1, after the literature review the guidelines identified and developed were incorporated into the existing 8 categories and subcategories of the building tool of the GREENSL® Rating System. Guidelines were incorporated in to the 8 categories under different levels such as incorporated as a new subcategory, incorporated as a new sub-prerequisite or a sub-credit under the existing credits and prerequisites and incorporated as a new minor improvement or an amendment done to sub-prerequisites & sub-credits. After the development and incorporation of guidelines into the existing 8 categories of the building tool of the GREENSL® Rating System, evaluation of those incorporated guidelines was carried out using expert committee meetings. 8 consecutive expert committee meetings were carried out with the participation of 10 experts and professionals from diverse disciplines and backgrounds related to research study such as green building and built environment professionals, green accredited professionals, disaster management experts, civil engineers, electrical and mechanical engineers, architects and engineering-based academics.

Many comments and inputs were suggested by the expert committee throughout the series of meetings for the improvement of the building tool of the GREENSL® Rating System for Built Environment as a disaster resilient tool. Those comments are, (1) Input DRR measures to reduce the risk caused due to lightening hazards, (2) Change few categories which the guidelines were directed and listed based on their relativity and most suitability while listing some guidelines under more than one category or credit/prerequisite (structural health monitoring checks in both commissioning and additional commissioning sub-categories), (3) Remove some guidelines which are already in the building codes, (4) Change criteria limits under certain credits and prerequisites (eg: 150% of rainwater harvesting storage) which will

Table 3 Structural and non-structural DRR and disaster resilient local guidelines and measures for floods, landslides and heavy winds

Natural hazard	Structural DRR measures	Non-structural DRR measures
Floods	Orientation: Placing short edge of the building to face flooding direction [18] Plan: aligning openings on opposite walls to generate a flow path for storm water [18] Slabs and foundations: concrete [19] Foundation: for problematic sub soil conditions pile foundations are suggested [19] Elevated buildings: raised plinth by building on higher grounds, creating elevated grounds and on silts [18]	Health monitoring and maintenance of the building A separate section/chapter about emergency handling mechanisms during a hazard (including fire) to be incorporated in to the building user guide [12] Develop an emergency preparedness information and instruction manual [12, 22] Implement sediment and erosion control plan to reduce the risk of occurrence and damage due to natural hazards [20, 23] Avoid constructions in inappropriate sites to reduce the vulnerability from natural hazards and carryout site assessment using hazard maps, topography and hydrology, etc. [11, 17] Identify the transportation needs of the people in an emergency by allocating required transportation facilities, resources and alternative evacuation routes [12] Enhancing the connectivity of community and transportation needs during an emergency through building alternative connections [12]

(continued)

Table 3 (continued)

Natural hazard	Structural DRR measures	Non-structural DRR measures
	Building superstructure: cross walls, heavy and the hollow blocks for wall construction, lintels on openings [18]	
	Amphibious buildings: boat type and lift type [20]	
	Flood proof construction materials: concrete, reinforced concrete framing, lime plastering or using magnesium oxide board as finishing [19]	
	Design wall to floor junction with two layers of waterproofing [20]	
	Use wet flood proofing technique [21]	
	Post-Flood Drainage Systems [20]	
	Water proof/tight construction (lower levels of buildings) [18, 20]	
Landslides	Site selection: ground slope (S) stability ($S < 5^0$: suitable for construction, $5^0 < S < 31^0$: apply engineering techniques, $S > 31^0$: not suitable for construction [18]	Limit disruption of natural water hydrology through watershed management technique [24] Provide access to public portable water transmission systems and wastewater conveyance networks during emergency situations [12] Rain water management systems should be adopted based on the future climate predictions and rain fall patterns [23] Installation of storm water collection and storage systems combined to rain water harvesting tanks with greater capacities, intensity and precipitation [12, 17] Design HVAC systems based on future climate changes and temperature variances, highlighting the energy resilience and natural hazards aspect All buildings in disaster prone areas shall use backup & emergency power sources and reliable communication systems [12] Install a wireless fire communication system to all large buildings in hazard zone areas as a backup system [12]
	Orientation: longer sides of the building should be parallel to the natural contour lines of the slope in a single platform [18]	
	Shape: simple and symmetrical shapes such as square or rectangular [18]	
	Earthworks: stable cut slopes in different soil types with or without a retaining wall [18]	
	Foundation: size and depth should be decided based on the type of subsoil and the bearing capacity of the soil and footings shall be constructed with enough edge distance for protection against erosion [18]	
	Construction of suitable earth retaining & slope stabilization structures [18]	

(continued)

Table 3 (continued)

Natural hazard	Structural DRR measures	Non-structural DRR measures
	Design and development of surface & sub-surface drainage networks along the slopes [18]	
	Landslide resilient construction: terraced buildings, elevated buildings on columns or raised footings [18]	
Heavy winds	Site selection: identification of the expected average wind speeds of the site location based on wind loading zonation maps; zone1: 50 m/s, zone 2: 42 m/s, zone 3: 38 m/s [18]	Use 100% renewable energy sources such as cogeneration & solar as reliable backup & emergency power sources during blackouts Take appropriate measures to safeguard toxic waste materials stored in flood prone zones [20] Install an emergency lighting control system to keep commercial & residential building stairwells, hallways and emergency exits lit during blackouts [12] Evacuation routes are developed as a part of public transportation systems [12] Design open public spaces in disaster risk areas and in vulnerable building premises [12] Emergency & First aid Kit to be stored in first floor to be used during an emergency [12, 22] Awareness programs for general public on natural disasters and their mitigation measures along with techniques related to preparedness Investing in disaster resilience by the local businesses and corporate citizens as a part of their corporate social responsibility are recognized and supported by the government [12] Hazard risk in land profiles are incorporated into land pricing [12] A tailored resource base is available to support disaster management plans in hazardous situations [12]
	Building sheltered using other structures or trees as a wind barrier. In hilly terrains, building should be located in a valley [18]	
	Orientation: shorter side of the building facing wind direction [18]	
	Plan: building openings on opposite walls creating flow path for wind [18]	
	Building shape: Avoid irregular shapes and go for simple regular shapes [18]	
	Walls: supported on all four sides with columns and beams, providing a stiffer wall against lateral wind forces [18]	
	Doors: provided with adequate connection to the walls on either sides and brickwork construction around the door frame [18]	
	Roof structure: avoid mono-pitch roofs and install hipped roofs and reinforced concrete flat roofs for high wind [18]	
	Roof connections: Roof connections between rafter, wall plate, reeper, ridge board, under-purlin & at roof should be properly chosen, designed and fixed according to standard guidelines based on the wind load, wind zone, building height and number of stories, etc. to increase the strength of the roof structure against high winds [18]	

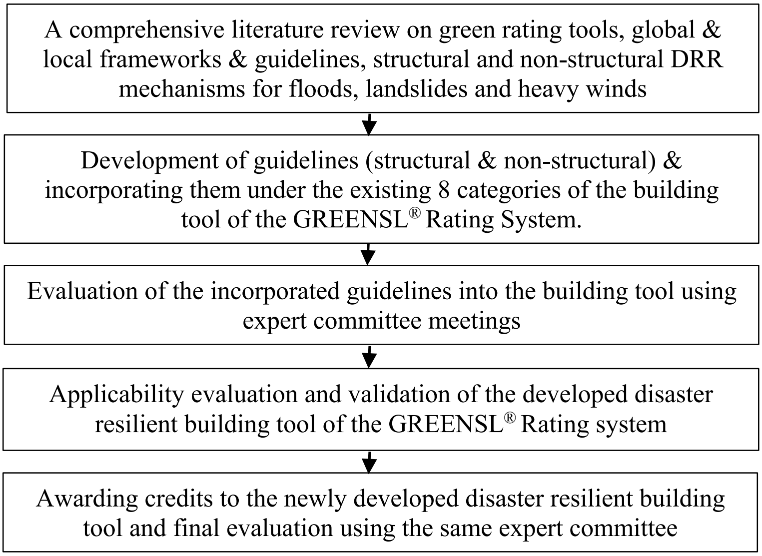

Fig. 1 Methodology used for developing a disaster resilient building tool of the GREENSL® rating system

result in enhancing the DRR and sustainability of the rating tool, (5) fire protection & detection mechanisms are suggested to include under commissioning clauses as a prerequisite as it was not an important aspect in the present rating tool, (6) Input a guideline to reduce the risks and enhance the resilience due to infections deceases like COVID-19, (7) Include some difficult achievables as 'Exemplary Performance' which may be difficult for the majority of green buildings, (8) Remove some criteria from the building tool due to the difficulty in achieving and transfer them to either city tool or transportation infrastructure tool or both based on the applicability and (9) Better not to mention about certain criteria such as slope stabilization criteria as they may vary with new research studies, instead mention only the link to refer the criteria.

After addressing the comments received from the expert committee, the new disaster resilient building tool of the GREENSL® Rating System for Built Environment consists of 2 new subcategories, 11 new sub-prerequisite or a sub-credit under the existing credits and prerequisites and 9 new minor improvement or an amendment done to sub-prerequisites & sub-credits. Initially the credits were awarded with points (starting from 1 point) depending on the importance and weightage of the DRR and disaster resilient guideline towards the greenery and sustainability of the building. Then the credited rating system was evaluated and reviewed using the same expert committee involved in evaluation of the incorporated guidelines. After the inputs and comments received from the expert committee, the rating system was re-credited with the suggested amendments and directed for the next round of review process. After couple of rounds of reviews by the expert committee, the credited rating system was ready for validation. Building Tool of the GREENSL® Rating system for Built Environment, incorporated with DRR and disaster resilient measures was comprised of extra 20 points, summing the total number of points into 120 points. The score card of the credited, disaster resilient building tool is shown in Table 4. Newly added content and the amendments done are underlined for better and clear identification purposes.

The credited new disaster resilient building tool was then directed for applicability evaluation and validation process. Applicability evaluation and validation were carried out through a series of surveys carried out using green certified buildings by GBCSL. Eleven certified buildings were chosen depending on their geographical location based on hazards and rating levels such that, 2 buildings located in flood prone areas, 3 based in landslide prone areas, another 3 in high wind areas and final 3 buildings located in less or zero hazard prone areas. Then the certified and scored project/building reports of above 11 buildings together with the building tool and newly developed disaster resilient building tool were used for the validation surveys. Score cards of the newly developed disaster resilient building tool were filled based on the current conditions and hazard vulnerability of the buildings. Then the new score card with the new certification type received based on new disaster resilient building tool was compared with the original or old score card with its certification type based on the existing building tool.

4 Results and Discussion

Although 20 points are allocated for DRR in this tool, points are allocated based on the applicable hazards for the respective building site. Therefore, number of applicable points may be varied depending on the location and vulnerable hazards. The summary of the 11 surveys conducted using the new disaster resilient building tool are analyzed and tabulated in Table 5. Points earned and the certification obtained using the existing building tool and the new disaster resilient building tool are compered while suggesting the possible and most effective applications of the tools.

According to Table 5, buildings situated in flood prone areas have dropped their certification at least by one level. Droppage of points has also varied between 8 and 9 points, highlighting the considerable impact on the certification obtained using the existing building tool. Therefore, it is better to use the new disaster resilient building tool in certifying the buildings situated in flood prone areas due to the high frequency and impact created by flood hazards on built environment in Sri Lanka. Same observation can be noticed the buildings situated in landslide prone areas as well. 7 to 8 points have dropped in all 3 surveys carried out while dropping the certification also by one level. Therefore, it can also be recommended to use the newly developed disaster resilient building tool to certify the buildings which are prone to landslides. One special aspect which can be noticed here is that all 3 buildings considered here have incorporated the basic design principles applicable to land slide hazard in constructing the buildings. There is a slight difference in the

Table 4 The score card of the credited, disaster resilient building tool of the GREENSL® rating system for built environment [17]

Prerequisite/credit	Criteria	Points	DRR points
1.0 MANAGEMENT (MN): 4 Total Points Available			
Prerequisite 1	Green Building Accredited Professional	Required	
Prerequisite 2	Commissioning Clauses	Required	
Prerequisite 3	Building users guide	Required	
Prerequisite 4	Emergency Preparedness and Information Manual		Required
Credit 1.1	Building Tuning [1 Point]		
	1.1.1. Occupant comfort and Energy Efficiency	1 Point	
Credit 1.2	Environmental Management [3 Points]		
	1.2.1. Involve Ecologist	1 Point	
	1.2.2. Environmental Management Plan	1 Point	
	1.2.3. Environment Mgt. System (ISO 14001)	1 Point	
2.0 SUSTAINABLE SITES (SS): 25 Total Points Available + Extra 10 Points for DRR			
Prerequisite 1	Erosion and Sedimentation Control	Required	
Credit 2.1	Site Selection [4 Points + 4 Points]		
	2.1.1. Inappropriate site avoidance to reduce environment impacts	4 Points	
	2.2.2. Inappropriate site avoidance to reduce the vulnerability		2 Points
Credit 2.2	Site Assessment and development [2 Points + 6 Points]		
	2.2.1. Site Assessment	2 Points	
	2.2.2. Architectural and design aspects which can withstand natural hazards		2 Points
	2.2.3. All hazard prone should use relevant hazard mitigation and preparedness measures		2 Points
Credit 2.3	Development Density and Community Connectivity	2 Points	
Credit 2.4	Brownfield Redevelopment and allowance for connectivity of Green Lands [1 Point + 2 Points]		
	2.4.1. Develop on a brownfield with required remediations	1 Point	

(continued)

Table 4 (continued)

Prerequisite/credit	Criteria	Points	DRR points
	2.4.2. Check the resilience of brownfield lands for potential hazards before redevelopment		1 Point
	2.4.3. Increase the resilience of the brownfield land		1 Point
Credit 2.5	Alternative Transportation [3 Points + 1 Point]		
	2.5.1 Public Transportation Access	1 Point	
	2.5.2. Parking Capacity	1 Point	
	2.5.3. Encourage use of green modes of transport	1 Point	
	2.5.4. Transportation during an emergency		1 Point
Credit 2.6	Reduced Site Disturbance [6 Points]		
	2.6.1. Protec/restore Habitat	2 Points	
	2.6.2. Vertical greening	2 Points	
	2.6.3. Development footprint	2 Points	
Credit 2.7	Storm Water Design, Quantity Control	2 Points	1 Point
Credit 2.8	Storm Water Design, Quality Control	2 Points	
Credit 2.9	Heat Island Effect, Non – Roof	1 Point	
Credit 2.10	Heat Island Effect, Roof	1 Point	
Credit 2.11	Light Pollution Reduction	1 Point	
3.0 WATER EFFICIENCY (WE): 14 Total Points Available			
Prerequisite 1	Eliminate potable water consumption for irrigation	Required	
Credit 3.1	Use of alternative water sources	1 Point	
Credit 3.2	Use of water-saving performances	1 Point	
	Exemplary Performance Marks (1)		√
Credit 3.3	Indoor water use reduction	1–4 Point	
Credit 3.4	Water Efficiency in air conditioning system	1 Point	
Credit 3.5	Innovative Wastewater Technologies [1–5 Points]		
	3.5.1. Reduce Potable Water Use	1 Point	

(continued)

Table 4 (continued)

Prerequisite/credit	Criteria	Points	DRR points
	3.5.2. Reduce potable water use or treat wastewater	1 Point	
	3.5.3. Harvested rainwater	2 Points	
	Exemplary Performance Marks (2)		√
	3.5.4. Aquifer Recharge	1 Point	
Credit 3.6	Innovative Water Transmission	1 Point	
Credit 3.7	Ground water recharge, if ground water is tapped	1 Point	
4.0 ENERGY AND ATMOSPHERE (EA): 22 Total Points Available + Extra 2 Points for DRR			
Prerequisite 1	Fundamental Building Systems Commissioning	Required	
Prerequisite 2	Minimum Energy Performance	Required	
Prerequisite 3	CFC Reduction in HVAC & R Equipment	Required	
Credit 4.1	Optimize Energy Performance	1–10 Points	
Credit 4.2	Renewable Energy [1 – 6 Points + 1 Point]		
	4.2.1. Renewable energy usage	1–6 Points	
	4.2.2. Renewable energy usage during emergencies		1 Point
Credit 4.3	Additional Commissioning	1 Point	1 Point
Credit 4.4	Ozone Depletion	1 Point	
Credit 4.5	Measurement & Verifications	1–2 Points	
Credit 4.6	Green Power	1 Point	
Credit 4.7	Certified Energy Auditor	1 Point	
5.0 MATERIAL, RESOURCE & WASTE MANAGEMENT (MR): 14 Points Available + 1 Point for DRR			
5.1 MATERIALS AND RESOURCES			
Prerequisite 1	Storage and collection of recyclables	Required	
Credit 5.1.1	Building Reuse [1–2 Points]		
	5.1.1.1. Maintain 75% of existing building and shell	1 Point	
	5.1.1.2. Maintain 75% of existing building structure and shell and 25% of non-shell areas	2 Points	
Credit 5.1.2	Resource reuse [1–2 Points]		

(continued)

Table 4 (continued)

Prerequisite/credit	Criteria	Points	DRR points
	5.1.2.1. for at least 10% of the Building	1 Point	
	5.1.2.2. for at least 20% of the Building	2 Points	
Credit 5.1.3	Recycled Content	1 Point	
Credit 5.1.4	Local/ Regional Materials	1 Point	
Credit 5.1.5	Rapidly Renewable materials	1 Point	
Credit 5.1.6	Certified wood and other building materials	1 Point	
Credit 5.1.7	Global Warming Potential of buildings	1 Point	
Credit 5.1.8	Materials Produced with Waste materials	1 Point	
<u>Credit 5.1.8</u>	<u>Hazard Resilient Building Materials</u>		<u>1 Point</u>
5.2 WASTE MANAGEMENT			
Credit 5.2.1	Construction Waste Management [1–2 Points]		
	5.2.1.1. for 50% recycling	1 Point	
	5.2.1.2. for 75% Recycling	2 Points	
Credit 5.2.2	Operational solid waste management	1 Point	
Credit 5.2.3	Hazardous Waste Management	1 Point	
6.0 INDOOR ENVIRONMENTAL QUALITY (EQ): 13 Total Points Available + <u>Extra 3 Points for DRR</u>			
Prerequisite 1	Minimum IAQ Performance	Required	
Prerequisite 2	Smoke (ETS) Control	Required	
Prerequisite 3	Minimum Acoustic Performance	Required	
Credit 6.1	Outdoor air delivering Monitoring	1 Point	
Credit 6.2	Increased Ventilation	1 Point	
Credit 6.3	Construction IAQ Management Plan	1 Point	
Credit 6.4	Low- Emitting Materials [1–3 Points]		
	6.4.1. Paints and Coatings	1 Point	
	6.4.2. Carpet Systems	1 Point	
	6.4.3. Composite Timber and Agrifibre Products	1 Point	

(continued)

Table 4 (continued)

Prerequisite/credit	Criteria	Points	DRR points
Credit 6.5	Indoor Chemical & Pollutant Source Control	1 Point	1 Point
Credit 6.6	Controllability of systems [1–2 Points + 1 Point]		
	6.6.1 Lighting controls	1 Point	
	6.6.2 Comfort controls	1 Point	
	6.6.3. Emergency Lighting		1 Point
Credit 6.7	Thermal comfort, design	1 Point	1 Point
Credit 6.8	Thermal comfort, verification	1 Point	
Credit 6.9	Daylight & Views [2 Points]		
	6.9.1 Daylight	1 Point	
	6.9.2 Views	1 Point	
7.0 INNOVATION & DESIGN PROCESS (ID): 4 Total Points Available + Extra 2 Points for DRR			
Credit 7.1	Innovation in Design [1–4 Points + 1–2 Points]		
	7.1.1 Innovation in design	1–2 Point	
	7.1.2 Exemplary performance	1–2 Points	1–2 Points
8.0 SOCIAL & CULTURAL AWARENESS (SC): 4 Total Points Available + Extra 2 Points for DRR			
Prerequisite 1	Archaeological sites & Heritage buildings	Required	
Credit 8.1	Social Wellbeing, Public Health & Safety [1–2 Points + 1–2 Points]		
	8.1.1. Enhance social wellbeing & public health	1–2 Points	
	8.1.2. Enchase public safety during emergencies		1–2 Points
	Exemplary Performance Marks (3)		√
Credit 8.2	Cultural Identity	1–2 Point	
Total Number of Points		100	20

scores and certification variation with the buildings situated in high wind areas. As most of the buildings considered here are placed in the east coastal belt of Sri Lanka, those buildings are also highly vulnerable to Tsunami risk as well. Although the scope of the research study was out of tsunami risks, during awarding the points, this aspect was taken into consideration. One of the positive aspects noticed in these selected green certified buildings are that they have considered the wind effect and alkaline effect (due to the locations are near the sea) in architectural and structural design aspects of the building. In these scenarios, points have been dropped by 6 or 7 points due to the moderate consideration of DRR measures against high winds in the

Table 5 Summary of the 11 surveys conducted using the new disaster resilient building tool of GREENSL® rating system for built environment

Project	Building type & location	Hazard vulnerability	Existing building tool		New disaster resilient tool	
			Points (%)	Certification	Points (%)	Certification
A	Factory & Stores—Badalgama	Floods	68	Gold	59	Silver
B	Factory—Millewa	Floods	74	Platinum	66	Gold
C	Administrative Building—Badulla	Landslides	64	Gold	56	Silver
D	Supermarket—Kegalle	Landslides	71	Platinum	64	Gold
E	Goods Factory—Pannala	Landslides	63	Gold	55	Silver
F	Cement Factory—Trincomalee	HW&T[a]	72	Platinum	65	Gold
G	Hospital—Batticaloa	HW&T[a]	67	Gold	60	Gold
H	Bank—Kalmunai	HW&T[a]	72	Platinum	66	Gold
I	University Building—Homagama	No vulnerability	68	Gold	65	Gold
J	Fuel Station Building—Pepiliyana	No Vulnerability	56	Silver	52	Silver
K	Hotel—Galgamuwa	No vulnerability	71	Platinum	68	Gold

[a]HW&T—Heavy Winds and Tsunamis

selected 3 buildings compared with their existing green certification. Other than one building, the certification level of the rest of the 2 buildings have dropped by one level. Therefore, it also can be recommended to use the building tool incorporated with DRR in certifying the buildings in high wind areas. If we have a look at the buildings which are situated out of any hazard vulnerable zones, the droppage of points were only limited to 3 or 4 points. Apart from one building, the rest of the certification levels remained same in the rest of the 2 buildings which the survey was conducted. Even that certification level drop was mainly due to the certification level being marginal to the lower limit of the certification. Therefore, it can be recommended to use the existing building tool in certifying the buildings which are not situated in hazard prone areas. However, incorporating the applicable general DRR measures of the new building tool incorporated with DRR measures is encouraged due to the increasing treads of natural hazards and climate change conditions in the present world and Sri Lanka which will be beneficial in transforming the green buildings into sustainable buildings.

5 Conclusions

Disasters induced by natural hazards are inevitable. Yet taking necessary DRR and disaster resilient measures become a vital necessity with the rapid increment in natural disasters which brings catastrophic damages to the environment, society and the economy. Disaster risk in Sri Lanka has been increasing mainly due to rapid unplanned commercialization and development of cities, infrastructure with poor quality, and the impacts of climate change which has exposed the built environment severely vulnerable to natural hazards. Out of all the hazards, floods, landslides, heavy winds and tsunamis are considered to be the events with highest number of occurrence and also with the highest number of losses and damages during last 30 years in Sri Lanka.

Although GBCSL has initiated encouraging sustainability and reduced consumption of energy and other resources usage in buildings, it could not specifically identify the need of integrating DRR mechanisms into their green rating tools. Even a platinum rated green buildings with lot of sustainable and green related concepts, cannot be sustainable in nature if they are not withstanding against the natural hazards. Therefore, incorporation of DRR and disaster resilient mechanisms into the residential and other buildings, is a transformation towards a sustainable built environment. This research concerns the recognition of structural and non-structural DRR measures for floods, landslides and high winds, developing guidelines and then coming up with a new disaster resilient building tool for GREENSL® Rating System for Built Environment under main 8 categories of the existing building tool for GREENSL® Rating System for Built Environment V2.0.

After developing the new disaster resilient building tool for GREENSL® Rating System, eleven surveys were carried out in green certified buildings situated in hazard vulnerable areas for the floods, landslides and high winds as well as less or no hazard prone areas. Those surveys reveled that, it is highly recommended to use new disaster resilient building tool in certifying buildings situated in floods and landslides prone areas, moderately recommended to use the new tool for certification in high wind areas and finally it is acceptable to use the existing building tool for GREENSL® Rating System for Built Environment V2.0 for the buildings situated in less or no hazard prone areas. However, it is advised that the new disaster resilient building tool is in use even for the buildings situated in less or no hazard prone areas by at least incorporating general DRR measures due to the increase of natural hazards and climate change conditions in the modern world and Sri Lanka which will be beneficial in the process of transforming normal buildings to green buildings.

6 Recommendations

There are number of important recommendations to be suggested at the end of my research work for future references and continuation of this research as follows,

- Some DRR guidelines may be difficult to achieve for a developing nation like Sri Lanka, where greening is also not a very popular concept due to the extra cost incurred. Therefore, incorporating DRR measures may incur another extra cost apart from greening.
- Some DRR measures contradict with greening and sustainability concepts such as zero-carbon emission, life cycle assessment and resources and energy resilience. As an example, use of concrete as a hazard resilient construction material and installation of HVAC systems predicting future climatic changes may consume more energy and recourses as well as emit more carbon to the environment which will contradict with green building concepts. Therefore, it's better to carry out a proper analysis to identify most sustainable options out of these concepts.
- Only 11 surveys were carried out due to lack of green certified buildings situated in hazard prone areas. Also, the recommendations to use the new disaster resilient building tool is in high, moderate, and no or low levels for different hazards or less or no hazard prone areas, it can vary depends on building type and its usage as well. Therefore, this tool can be further developed as a more practical tool if more surveys can be conducted.

Acknowledgements This study was conducted with the help, support and directions of Green Building Council of Sri Lanka (GBCSL). They immensely supported by providing their resources such as green rating tools and systems, green certified building information, green certified project reports and their professionals as well.

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