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Post-Earthquake Reconstruction in Kathmandu Valley: Progress and Challenges

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Abstract

The 2015 Gorkha earthquake in Nepal inflicted significant human casualties and economic losses, highlighting the need for improved construction techniques and seismic safety measures. This study examines the post-earthquake scenarios, types of earthquake-induced damages, reconstruction methodologies, and reconstruction progress in Kathmandu Valley. The dominant pre-earthquake building types were Reinforced Cement Concrete (RCC) structures in Kathmandu, and Stone Mud Mortar (SMM) and Brick Mud Mortar (BMM) structures in Bhaktapur. The earthquake caused extensive damage to both reinforced and non-reinforced masonry structures due to their low strength and poor construction practices. Failures included wall separation, in-plane, and out-plane failures, overturning, and floor collapse. The reconstruction efforts have been primarily focused on private housing, with progress varying across different sectors. While private housing has seen satisfactory reconstruction, public heritage sites, buildings, educational and health institutions, and government structures lag behind. Retrofitting techniques have proven to be more cost-effective than rebuilding RCC structures. The preference for SMM and BMC structures persists in other regions. This abstract provides a concise overview of the article's key findings regarding post-earthquake reconstruction in Kathmandu Valley, emphasizing the need for accelerated efforts to restore public infrastructure and heritage sites.

Keywords: Earthquake, reconstruction, reinforced, retrofitting, restoration

Background

The Gorkha earthquake, also known as the Nepal earthquake of 2015, struck on April 25th, with its epicenter located in the Gorkha district of Nepal. It was a devastating 7.8 magnitude earthquake that caused widespread destruction across the region. The human toll of the disaster was immense, with over 8,000 lives tragically lost and around 22,000 individuals injured. The tremors displaced hundreds of thousands of people, forcing them to seek shelter in makeshift camps lacking basic amenities and sanitation. Vulnerable communities in remote areas were particularly hard hit, making access to essential aid and support a daunting challenge. The effects of the Gorkha earthquake were particularly felt in the Kathmandu Valley, a densely populated and historically significant area, where numerous buildings, including heritage sites and public institutions, were severely damaged or reduced to rubble. The earthquake exposed the vulnerability of existing construction techniques and seismic safety measures, highlighting the urgent need for improved building practices and reconstruction efforts in Nepal.

Introduction

The Gorkha earthquake of 2015 was a devastating event that left a profound impact on Nepal, causing widespread destruction and loss. The consequences were not only measured in terms of the lives tragically lost but also in the extensive damage incurred across various sectors of society. The economic toll of the earthquake was significant, with substantial losses affecting communities and businesses. The earthquake's powerful forces wreaked havoc on numerous public and private structures, leaving no corner of society untouched. Residential buildings, schools, hospitals, cultural heritage sites, and historical monuments were among the many structures that suffered damage during the seismic event. Despite the immense tragedy, this unfortunate earthquake presented a unique and invaluable opportunity for researchers and experts to study the failure patterns exhibited by different types of buildings when subjected to seismic forces. By conducting in-depth analyses of these failures, valuable insights and lessons were gained, providing an essential foundation for improving construction techniques and enhancing structural resilience. Understanding the weaknesses and vulnerabilities that led to the destruction of various buildings allows us to learn from the past and develop better strategies to prepare for future disasters.

Moreover, the earthquake served as a crucial platform for comprehending the seismic performance of public residential buildings. The losses and damages incurred during the earthquake provided a compelling case study to shed light on the effectiveness of reconstruction methods used for different building types. This comprehensive study not only highlights the earthquake-induced damages and challenges faced during the reconstruction process but also showcases the progress made to date in addressing these complex issues. Through diligent research and analysis, this study aims to foster a deeper understanding of earthquake impacts and the subsequent reconstruction efforts in the Kathmandu Valley and beyond. It emphasizes the importance of collaboration among researchers, policymakers, architects, engineers, and the public to work together toward building a safer and more resilient society. By learning from this tragic earthquake, we can collectively improve construction practices, implement effective measures to reduce vulnerability and develop disaster preparedness strategies that safeguard our communities and their invaluable cultural heritage. As we continue to navigate the path toward recovery and rebuilding, the insights gleaned from this study stand as a testament to our determination to build a safer, more secure, and sustainable future for Nepal and beyond.

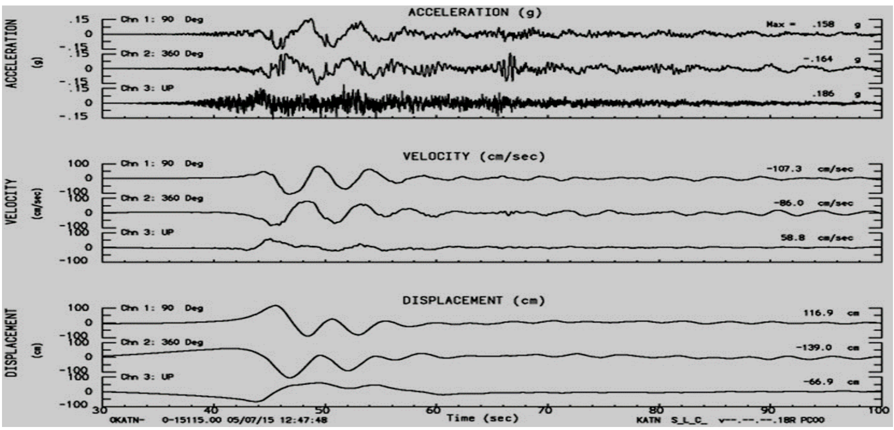


Figure 1: Kanti Path, Kathmandu, Nepal (USGS Sta KATNP), Record of April 25, 2015, 6:11:46.6 GMT (Filtering: Highpass at 02 Hz (50 sec) USGS Strong Motion Processing.

In the above figure, the displacement graph shows the ground's movement or the motion of a specific point on the Earth's surface over time, indicating how much the ground deviates from its initial position. It provides information about the amplitude and duration of the ground movement. The velocity graph, on the other hand, illustrates the speed at which the ground is oscillating during the earthquake, showing how fast the displacement is changing with time. It provides insights into the rate of movement. Lastly, the acceleration graph represents the rate of change of velocity or the acceleration of the ground motion, demonstrating how quickly the velocity is changing. It indicates the ground's acceleration and deceleration during the earthquake. Together, these graphs offer crucial data to analyze the intensity of loss and the potential impact of the earthquake on structures and the human population.

The overall loss in Nepal caused by the 2015 Gorkha earthquake was around $7 billion. Similarly, the total cost of reconstruction estimated by the National Reconstruction Authority (NRA) in 2015 was around Rs.938 billion**.** Both, damaged and undamaged structures have given us an opportunity to rectify our construction techniques to make them safe against seismic activities. The current study highlights post-earthquake scenarios, general types of earthquake-induced damages in structures, reconstruction methodology, and progress of reconstruction till present in Kathmandu Valley.

Figure 2: Out-of-plane collapse of facade wall seen in Kathmandu Valley (Varum et al., 2018)

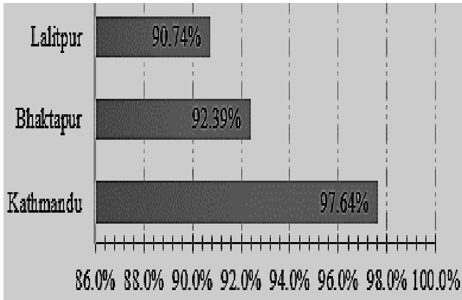


Figure 3: Progress of reconstruction of Private housing in Kathmandu Valley (NRA, 2021)

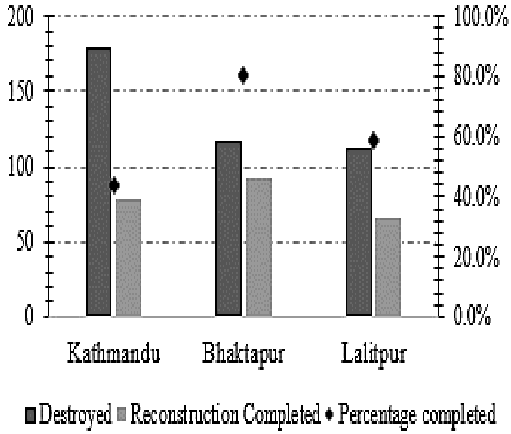
Districts	**House Destroyed**	**Resconstruction Completed**
Kathmandu	45236	44167
Baktapur	28513	6343
Lalitpur	29273	26561

Table 1. Number of Houses destructed and recostructed in Kathmandu valley (NRA, 2021)

Prior to the 2015 earthquake, Reinforced Cement Concrete (RCC) structures were dominant in the Kathmandu district. In the Bhaktapur district, Stone Mud Mortar (SMM) and Brick Mud Mortar (BMM) structures were dominant whereas in Lalitpur, the typology of structures was even between these three types. After the earthquake, 45,236 private houses were completely destroyed in Kathmandu while 28,513 and 29,273 private houses were destroyed in Bhaktapur and Lalitpur as shown in

Table *1*. Most damaged structures were unreinforced and low-strength masonry due to their low strength and lack of guidelines in the past when they were constructed. RCC structures were also damaged due to poor workmanship and the use of cheap and poor construction materials. The most common types of failures observed in structures were return wall separation and overturning of façade, in-plane failure, out-plane failure, overturning, diaphragm movement, floor collapse, etc. Typical out-plane failure of the façade wall is shown in Figure 2. The condition of the reconstruction of private housing in Kathmandu Valley is shown in Figure 3 & 4.

Figure 4: Progress of reconstruction of archeological structures in

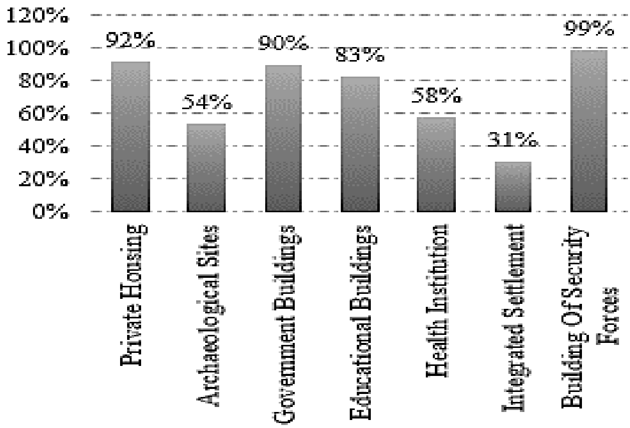


Kathmandu valley (Sharma et al., 2018)

During an earthquake, 920 archeological structures were damaged, out of which 170 belong to a world heritage site. The progress of the reconstruction of archeological structures is shown in Fig. 4. In Kathmandu Valley, 406 archeological structures were destroyed. In the Kathmandu district, out of 178 destroyed heritage, 78 have been reconstructed. In Bhaktapur district, 93 out of 116 have been reconstructed whereas in Lalitpur district, 66 out of 112 have been reconstructed.

The condition of reconstruction of different buildings in affected districts is represented in Fig. 5. The Total number of educational institutions that collapsed during the earthquake was 7,553 and 6,246 has been reconstructed. 1197 health institutions collapsed over which 698 have been reconstructed. 374 out of 415 government buildings have been reconstructed. 214 out of 216 buildings of security forces have been reconstructed. 493 out of 920 archaeological sites have been reconstructed.

Figure 5: Types of buildings and their reconstruction condition (RSS, 2021)



The reconstruction is done either by strengthening partially damaged structures with appropriate retrofitting techniques or by constructing new buildings as a whole following guidelines set by NRA. Cost analysis showed that retrofitting is much more cost-effective than the reconstruction of new RCC buildings in Kathmandu Valley (Sthapit & Sthapit, 2021). However, Stone Mud Masonry (SMM) and Brick Cement Masonry (BCM) are still preferred in other regions over RCC structures. In the reconstruction process, 47.1% of new buildings were SMM followed by 32% of BMC and 14.4% of RCC (Adhikari & D'Ayala, 2020)

Figure 6: Types of buildings in Nepal

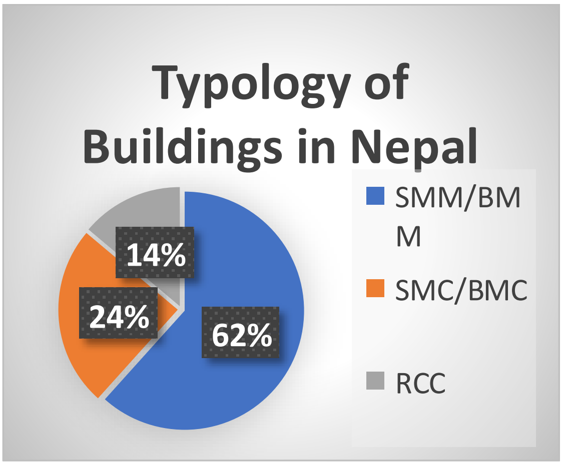


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Figure 7: Types of buildings in Kathmandu

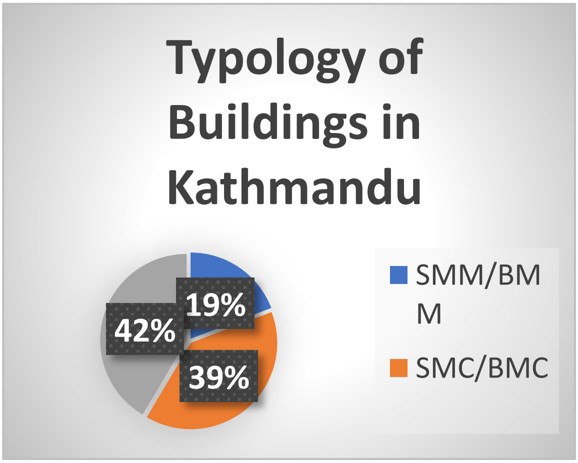

Figure 8: Types of buildings in Bhaktapur

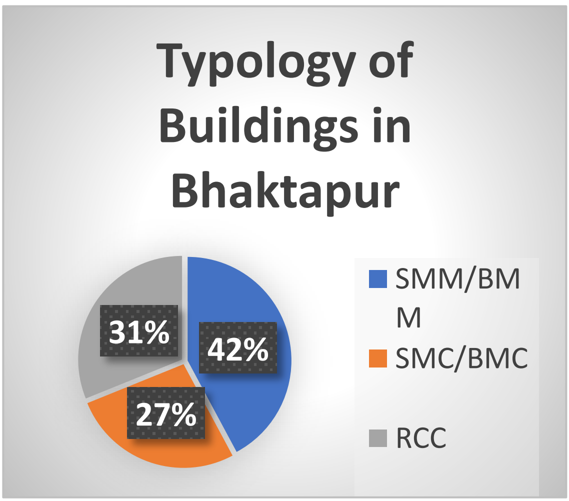

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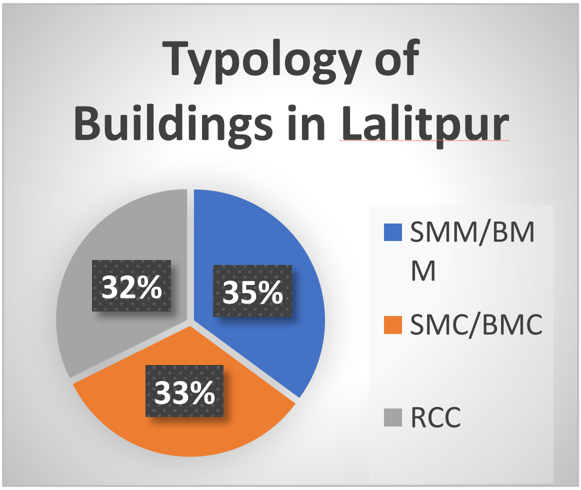
Figure 9: Types of buildings in Lalitpur



Based on the data presented in Figures 6, 7, 8, and 9, it is evident that the prevalent building materials in Nepal are brick or stone with mud masonry. However, within the valley, the proportion of SMM and BMM buildings is relatively lower, with Kathmandu showing the smallest proportion of such structures. Conversely, RCC structures dominate in Kathmandu, while Bhaktapur still maintains SMM and BMM buildings as the primary type, and in Lalitpur, the distribution of building typologies is more evenly balanced among the three types.

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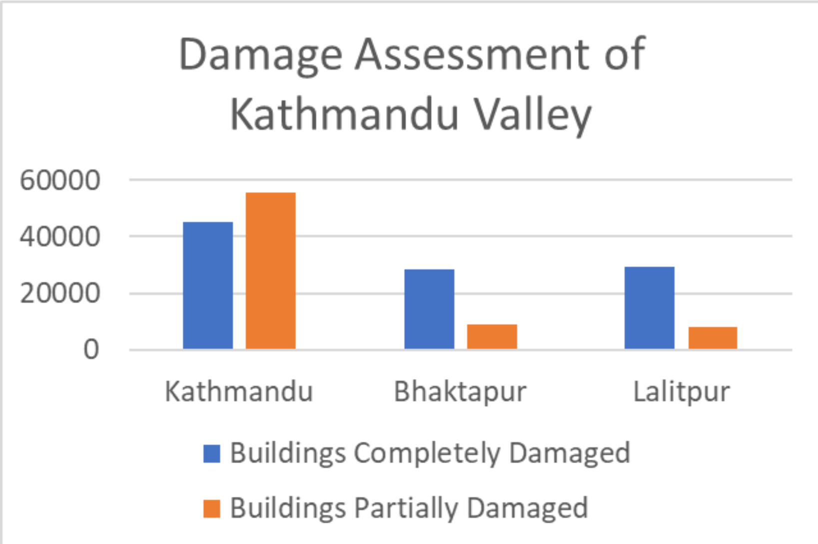
Figure 10. Damage assessment of Kathmandu Valley



According to the chart, Kathmandu exhibits the highest count of damaged buildings compared to the two other districts in the valley. However, an interesting distinction is observed in the types of damage, as Kathmandu has a greater number of partially damaged houses, whereas the other two districts have a higher proportion of completely damaged buildings and fewer partially damaged ones. This can be attributed to the fact that Kathmandu has a higher proportion of RCC buildings than Stone or Brick Masonry structures.

After the devastating Gorkha earthquake in 2015, the reconstruction efforts in the affected regions were carried out through two primary approaches: retrofitting and constructing new buildings. Retrofitting, a meticulous and resourceful process, involved the thorough assessment and strengthening of damaged structures, aiming to fortify their structural integrity and enhance their resilience against future earthquakes. This method acknowledged the historical and cultural significance of existing buildings while modernizing

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them to meet contemporary safety standards. On the other hand, the construction of new buildings focused on incorporating state-of-the-art seismic-resistant techniques, employing cutting-edge engineering and architectural innovations to create safer and more resilient communities. The overarching goal was to minimize future losses, protect lives, and ensure the sustainable development of these areas, leaving a lasting legacy of resilience and preparedness in the face of natural disasters.

Figure 11: The Total Cost of Reconstruction

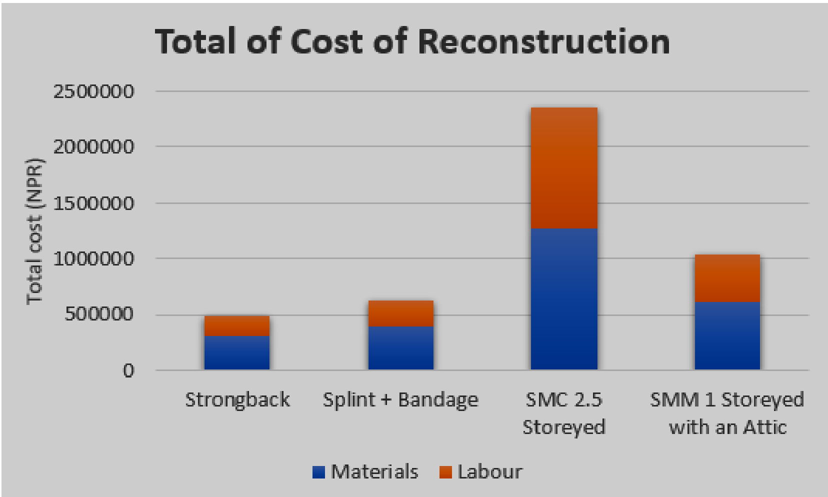

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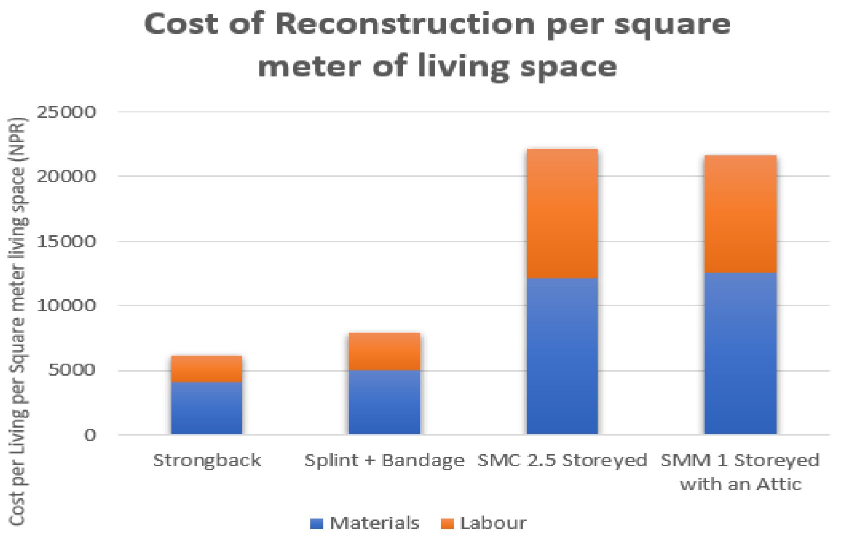
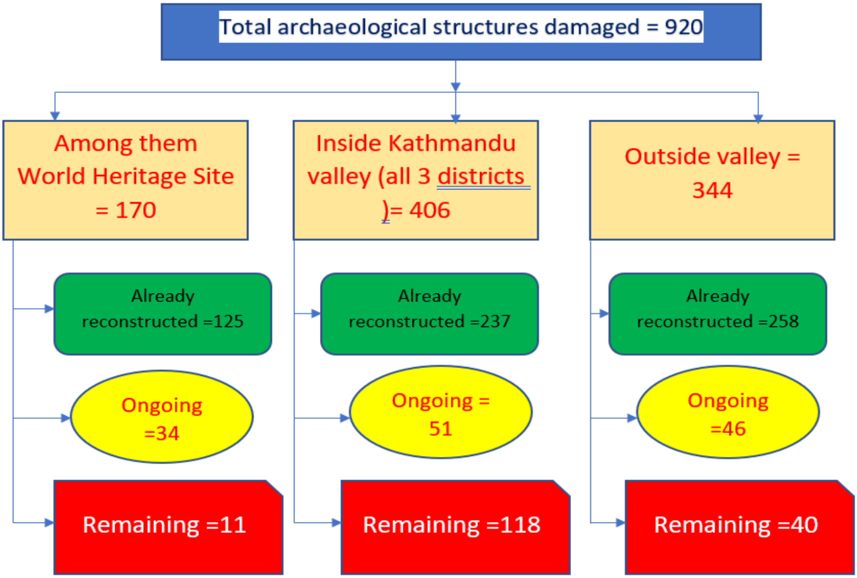
Figure 12: Cost of reconstruction per square meter of living space



The analysis presented in Figures 11 and 12 demonstrates that retrofitting is a more cost-effective strategy for reconstruction. While building a new one-storeyed SMM (Semi-Mechanically Manufactured) structure with an attic might seem initially comparable in cost to retrofitting, the cost per square meter of living space in SMM buildings turns out to be significantly higher due to their limited capacity, resulting in inadequate living space. Moreover, among the various retrofitting methods, the Strong Back method proves to be more cost-effective than the Splint and Bandage method.

Following the 2015 Gorkha earthquake, there was substantial damage to cultural heritage sites, demanding a concerted effort towards reconstruction. This involved a systematic approach, including damage assessment, prioritization of restoration based on historical significance, and the involvement of experts to maintain authenticity. A comprehensive account of the Heritage Damage and Reconstruction process is depicted in Figure 13 below.

Figure 13: Heritage Damage and Reconstruction by Earthquake 2015



Effect On Cultural Heritages and Monuments all over Nepal by Earthquake of 2015 A.D. Report estimates are $160 million to restore 1000 damaged and destroyed monasteries, temples, historic houses, and shrines across the country. Major effects are in the following heritages:

1. Swayambhu
2. Kathmandu, Bhaktapur and Patan Durbar Square
3. Pashupatinath temple
4. Changu Narayan temple
5. Sankhu temple
6. Krishna mandir

Figure14: *The status of reconstruction vs damaged structures*

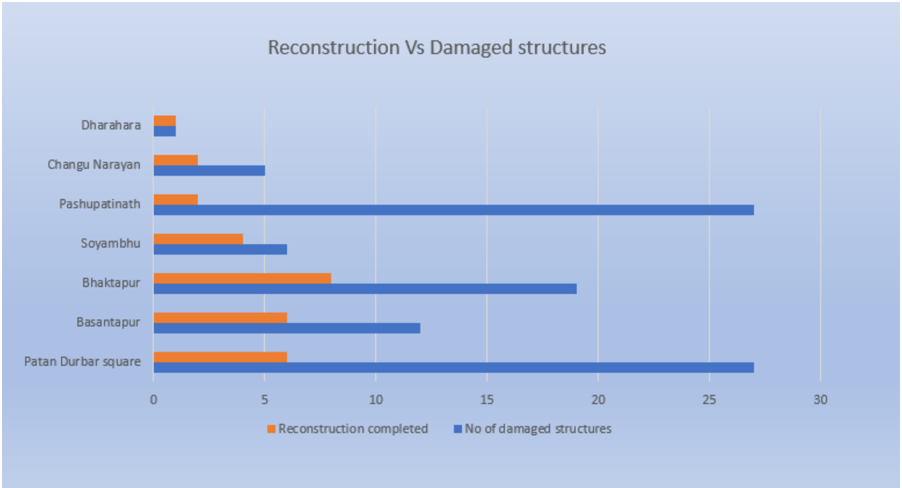
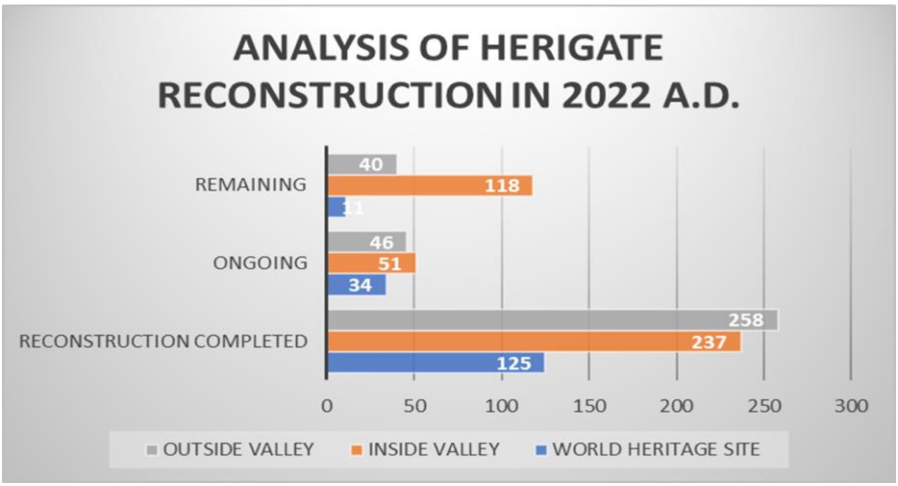


Figure 15: *Analysis of remaining, ongoing, and reconstructed heritages*



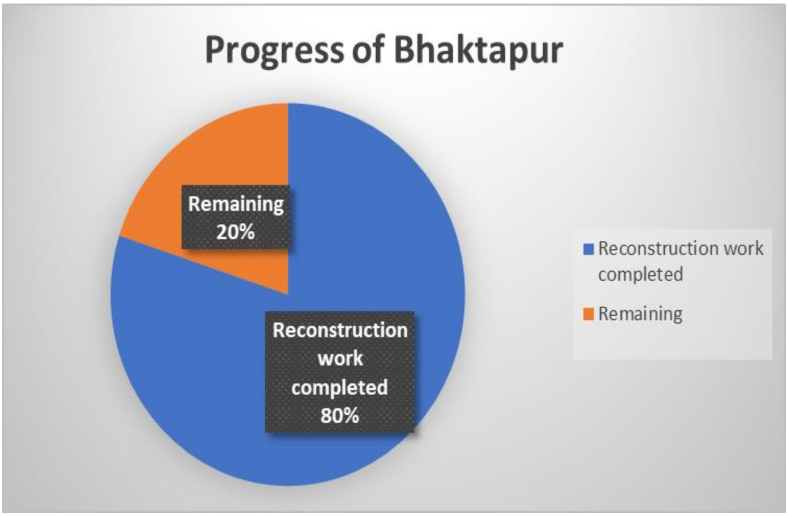
IN KATHMANDU DISTRICT:

The status of reconstruction in Kathmandu Valley (Source: The Kathmandu Post) is given below table:

DESCRIPTION	Damaged	Reconstruction completed	Reconstruction ongoing
Monuments belonging to 4 world heritage site	178	78	35

IN BHAKTAPUR DISTRICT:

Figure 16: The status of reconstruction progress in Bhaktapur



As shown in Figure 16, as of 2020, the historic city of Bhaktapur had made significant progress in its restoration and reconstruction efforts, with an impressive 80% of the work already completed. One of the remarkable aspects of this restoration process was the city's ability to maintain autonomy, as the Department of Archaeology was responsible for less than 10% of the restoration efforts on the numerous heritage sites. Instead, the majority of the fundraising and reconstruction endeavors were carried out through local cooperation, with the Bhaktapur municipality taking the lead in renovating a staggering 104 monuments and temples. An outstanding example of this collaborative effort was the restoration of the Nyatapola temple, which alone required a substantial investment of Rs. 3.5 million. Thanks to the generous donation of Rs. 1.5 million from the public, progress was made on this remarkable temple's restoration. Despite these significant achievements, the restoration process faced unforeseen challenges that led to delays in its completion, most notably the global COVID-19 pandemic that impacted various aspects of daily life, including construction activities and project timelines. Nevertheless, Bhaktapur's commitment to preserving its rich cultural heritage has persevered, and the community's collective efforts continue to propel the restoration project forward, ensuring the city's historical gems remain intact for generations to come.

IN LALITPUR DISTRICT:

In Patan Durbar Square, out of a total of 35 heritage that suffered varying degrees of damages, restoration works on 12 have been completed and 8 are undergoing reconstruction.

DESCRIPTION	Damaged	Reconstruction completed	Reconstruction ongoing	Remaining
Heritage of Patan Durbar Square	35	12	8	15

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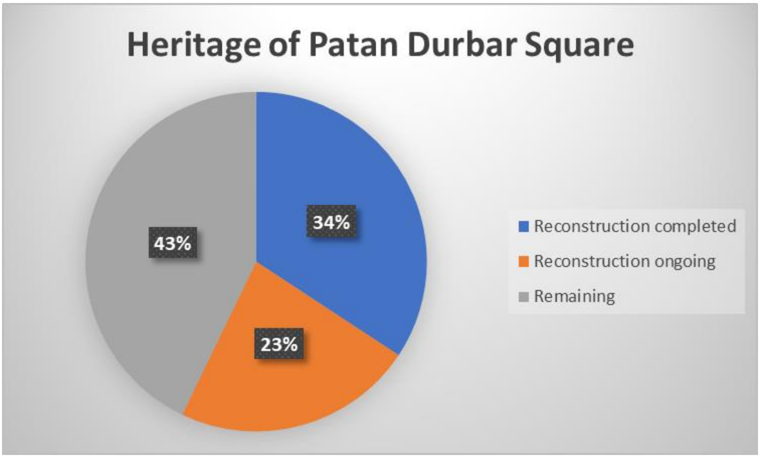
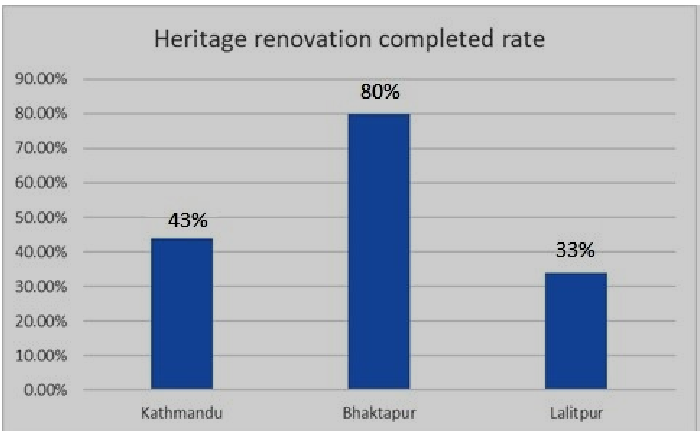
Figure 17: The status of reconstruction progress in Patan Durbar Square



Overall, in Heritage Reconstruction Bhaktapur district is leading with the highest number of completed reconstruction works after the earthquake.

Figure 18: Comparison of Heritage renovation completed rate within Ktm Valley



This study discusses the brief history of the earthquake in Nepal, the major timeline of the 2015 Gorkha earthquake, the damage assessment of the earthquake, a surface case study of foreign aid given to Nepal and its management, and the progress of the reconstruction of damages.

The major focus of this study is on the damages and modes of failure of buildings in different sectors of Kathmandu Valley namely Heritages (Tourism), Housing and Health, etc. The most affected sector in Kathmandu Valley was the housing sector with Tourism following in second. In the housing sector, as well, unreinforced and low-strength masonry were the buildings that were most damaged due to their low strength and lack of guidelines in the past when they were constructed. RC buildings were also damaged due to poor workmanship and the use of cheap and poor construction materials. In the health sector as well, just one hospital suffered partial damage with Health posts suffering the most followed by private sector facilities.

This study also discusses the reconstruction techniques used inside the valley. Reconstruction was done either by strengthening partially damaged structures or by the construction of new buildings as a whole following the guidelines set by the National Reconstruction Authority. Cost analysis showed that retrofitting was much more cost-effective than constructing a new building. For the construction of new buildings as well, due to their cost-effective nature, people still prefer Stone with Mud Masonry and Brick with Cement Masonry over RCC structures which are preferred by only a few.

Discussions and Conclusion

The 2015 Gorkha earthquake in Nepal highlighted the urgency for improved construction and seismic safety measures. The study examined post-earthquake scenarios, damages, and reconstruction in Kathmandu Valley, where RCC structures were dominant. Both reinforced and non-reinforced masonry structures suffered extensive damage due to poor construction practices. The progress of reconstruction in Kathmandu Valley had only been satisfactory in private housing sectors whereas the public heritages and public buildings still lack behind. Similarly, the rate of reconstruction of security forces building is higher compared to others. Also, retrofitting proved cost-effective for rebuilding RCC structures. Encouraging safer construction practices in regions favoring SMM and BMC structures is essential. This study emphasizes the need for accelerated efforts, involving the government, private sector, and communities, to restore public infrastructure, preserve Nepal's cultural heritage, and build a resilient future.

In my opinion, the sluggish progress of reconstruction in the Kathmandu Valley can be attributed to a combination of technical, financial, bureaucratic, and social factors. Although the government has taken some steps to address these challenges, greater commitment and collaboration among all stakeholders are needed to expedite the reconstruction process. One significant concern is the prioritization of private housing sectors over public buildings and cultural heritage sites. While addressing housing needs is crucial, neglecting the restoration of public infrastructure and historical landmarks could have long-term repercussions on the nation's identity, tourism potential, and overall resilience. To overcome this drawback, it is essential for the government to allocate more resources and attention to preserving public heritage and infrastructure.

Another obstacle lies in the slow adoption of seismic retrofitting for reinforced concrete structures. Despite its proven cost-effectiveness in enhancing earthquake resilience, building owners and developers may exhibit reluctance to invest in retrofitting due to perceived costs and disruptions. Encouraging policies that incentivize or mandate seismic retrofitting for existing structures would be a prudent step toward creating a safer urban environment. Moreover, regions favoring non-reinforced masonry (NRM) and brick masonry construction (BMC) face their own unique challenges. These traditional construction methods deeply rooted in local culture may resist change. Promoting safer construction practices in such areas requires a comprehensive approach involving awareness-raising about seismic risks, technical support, and active community engagement. Striking a balance between preserving cultural heritage and ensuring safety through innovative retrofitting techniques is crucial in these regions. The role of good governance can also not be forgotten in this regard.

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