RGC Ref. No.:
UGC/FDS25/E05/21
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines:
1. *Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.*
2. *Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

A Machine Learning Framework for Vulnerability Assessment of Buildings

2. Investigator(s) and Academic Department(s) / Unit(s) Involved

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	LUK Sung Hei / Lecturer	Civil Engineering / Department of Construction, Environment and Engineering / Technological and Higher Education Institute of Hong Kong
Co-Investigator(s)	N/A	N/A
Others	N/A	N/A

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	1st Jan 2022	N/A	N/A
Project Completion Date	31st Dec 2023	30th Jun 2024	13th Oct 2023
Duration *(in month)*	24 months	30 months	13th Oct 2023
Deadline for Submission of Completion Report	31st Dec 2024	30th Jun 2025	13th Oct 2023

4.4 Please attach photo(s) of acknowledgement of RGC-funded facilities / equipment.

N/A

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. Explore the applications of machine learning techniques on vulnerability assessment of buildings, and compare their effectiveness;

2. Establish a reliable method to represent the damage levels of buildings;

3. Develop a ML-based prediction model to estimate the seismic performance and damage states of buildings;

4. evelop a systematic and efficient methodology for vulnerability assessment of buildings

5.2 Revised objectives

Date of approval from the RGC: N/A

Reasons for the change: N/A

1.

2.

3. ..

5.3 Realisation of the objectives

(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any)

The first objective (100% achieved) is to explore the feasibility of using machine leaning (ML) and effectiveness of different machine learning models / algorithms in developing prediction models for seismic performance assessment. In the project, a variety of ML algorithms have been investigated in detail, including basic algorithms (e.g., support vector machine, decision tree, etc.), ensemble models (e.g., stacking method, boosting method, etc.) and artificial neural networks (vanilla and ensemble). Prediction models were developed using the aforementioned algorithms using the datasets generated via extensive time-history analyses. Their effectiveness of each model was compared by evaluating their performance via representative evaluation metrics (e.g., accuracy and precision). The results showed that ensemble methods, particularly boosting algorithms, performed the best for developing prediction models based on tabular datasets. Vanilla neural network-based models were normally under-performed compared with boosting algorithms, unless the neural network models were enhanced using ensemble techniques. This finding is valuable for selecting suitable algorithms for developing effective data-driven based prediction models.

The second objective (100% achieved) is to develop a reliable method to represent the damage levels of buildings. The study developed prediction models using tabular datasets generated via extensive time-history analyses. From the analysis results, the maximum inter-story drift ratio was used to classify damage levels of buildings for training the prediction models. By providing suitable input parameters, such as structural and earthquake properties, the possible damage levels of buildings can be estimated using prediction models.

The third objective (100% achieved) is to develop ML-based prediction models based on effective algorithms to estimate the seismic performance and damage states of buildings. The study developed efficient and accurate prediction models to rapidly predict damage levels and maximum inter-story drift ratios of RC buildings under different levels of earthquakes without relying on time-consuming analyses.

The fourth objective (100% achieved) is to develop a systematic and efficient methodology for vulnerability assessment of buildings. The developed prediction models required input parameters to assess the seismic performance of buildings. By systematically collecting the required structure properties (e.g., height and width of building, column axial load level, fundamental period of vibration, etc.), and earthquake characteristics (e.g., peak ground acceleration, peak ground velocity, spectral acceleration, etc.), the damage classes/levels of buildings can be estimated rapidly. The results are valuable for safety assessment of buildings or for planning future renovation works. Instead of damage classes, prediction models can be used to estimate the inter-story drift ratios of buildings to better understand how the buildings behave under a given level of earthquake. The prediction models don't require time-consuming processes to generate the outputs, and so, they are capable of applying large-scale vulnerability assessment of buildings.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. *Explore the applications of machine learning techniques on vulnerability assessment of buildings, and compare their effectiveness*	√	100%
2. *Establish a reliable method to represent the damage levels of buildings*	√	100%
3. *Develop a ML-based prediction model to estimate the seismic performance and damage states of buildings*	√	100%
4. *Develop a systematic and efficient methodology for vulnerability assessment of buildings*	√	100%

6. Research Outcome

6.1 Major findings and research outcomes
(Maximum 1 page; please make reference to Part C where necessary)

The study conducted detailed investigation on the contents of integrating machine learning and seismic vulnerability assessment of buildings. The outcomes of the study are valuable to provide an efficient and rapid way to assess building performance under earthquakes and for future development of more complicated prediction models. The key findings of the study are summarized in the following paragraphs. First, a detailed investigation was conducted on the classical machine learning algorithms and the advanced algorithms, such as ensemble methods and neural network models (Luk, 2023). The characteristics of different machine learning algorithms were explored and then applied for developing prediction and classification models for reinforced concrete (RC) buildings under different levels of earthquakes.

Second, prediction models were developed to meet the needs for assessment of seismic performance of buildings. A comprehensive dataset was generated via numerous non-linear time-history analyses. The prediction models were developed based on structure and earthquake parameters, presented in a tabular format. In addition to classical algorithms, such as support vector machine and decision tree, advanced methods, such as boosting methods, stacking methods, and neural networks were applied to develop prediction models (Luk, 2023). Two types of prediction models, namely response's prediction model and damage level classification model, were developed. The former one can predict the maximum inter-story drift ratios of RC buildings based on simple input parameters to understand the seismic responses of buildings without the need for comprehensive non-linear time-history analysis. The classification models can identify the possible damage levels of buildings under different earthquake magnitudes. The models are essential for conducting large-scale vulnerability assessments involving numerous buildings.

Third, the efficiency and performance of a variety of machine learning algorithms were investigated in detail in the current study. In addition, the setting of different architectures for neural network models was studied extensively. The results revealed that boosting algorithms, particularly the XGBoost methods, were suitable for the development of prediction models (Luk, 2023). The performance of vanilla neural networks was normally under-performed compared with boosting methods. In the latter part of the project, neural networks were combined with ensemble methods to enhance the models' performance. These results provide useful direction for future development of efficient and accurate prediction models to estimate seismic performance of buildings and structures.

In summary, the study developed prediction models using data-driven approaches to facilitate seismic response prediction and damage level classification for buildings subjected to earthquakes. These models integrate advanced machine learning techniques, enabling rapid assessment of structural performance based on key parameters, such as building geometries and earthquake characteristics. By studying the performance of classical algorithms and advanced methods like boosting and bagging algorithms, prediction models can achieve high accuracy and efficiency. These predictive tools allow engineers to rapidly estimate maximum inter-story drift ratios and identify potential damage levels, offering invaluable insights for large-scale seismic vulnerability assessments. The models also can be used for urban planning and the development of mitigation strategies aimed at reducing structural risks and safeguarding communities against earthquake-induced damage.

Reference

Luk, S.H. (2023), "Damage Class Prediction using Machine Learning Algorithm", *The 2023 World Congress on Advances in Structural Engineering and Mechanics* (ASEM23), Seoul, Korea on August 16-18.

6.2 Potential for further development of the research and the proposed course of action *(Maximum half a page)*

The outcomes of the study provided invaluable insights in the application of data-driven approaches. Based on the results of the study, web-based prediction models can be developed for rapid identification of potential risk of buildings under different levels of earthquakes without the need for comprehensive finite element analysis. Together with the available open data nowadays, the prediction model could be used to conduct large-scale seismic vulnerability of buildings to identify the buildings at risk under different levels of future earthquakes.

In addition to the developments of prediction models, more investigations on the use of cutting-edge algorithms, such as transformer architecture, transfer learning and graph neural networks, could be explored to further enhance the performance and capability of the data-driven prediction models and expand the range of input data formats for the prediction models. Other data formats, such as industry foundation classes (IFC), graph-structured data could be potential input data for data-driven approaches.

7. Layman's Summary

(Describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

Assessing the seismic vulnerability of buildings and structures is a crucial aspect of civil engineering, aimed at safeguarding communities and minimizing damage during earthquakes, which is known as a destructive disaster that may lead to damage or collapse of buildings. Hence, recognizing the seismic risks associated with buildings is crucial for planning future renovation works that prioritize the protection of human lives. However, assessing seismic performance of buildings normally takes a long time and involves large computational efforts. The research project aims to investigate an efficient and accurate technique via machine learning to rapidly assess the seismic performance of buildings. In the study, the methodology and suitable machine learning algorithms for prediction models' development were investigated deeply. The results involved detailed comparison of performance and effectiveness of different algorithms in vulnerability assessment of buildings and development of accurate prediction models to estimate the seismic responses of buildings. The models can rapidly identify the performance levels of buildings by providing representative input parameters. They are helpful for large-scale seismic vulnerability assessments. Furthermore, these tools offer critical support for decision-making processes in urban planning and disaster mitigation.

Part C: Research Output

8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project

(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) *(denote the correspond-ing author with an asterisk*)*	Title and Journal / Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the Institutional Repository *(Yes or No)*
Year of Publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*						
N/A	N/A	✓	N/A	LUK Sung Hei*	Damage Classification of RC Buildings based on Machine Learning / *Buildings*	No	Yes	Yes	N/A
N/A	N/A	N/A	✓	LUK Sung Hei*	Data-driven approaches for structural response estimation under earthquakes	No	Yes	Yes	N/A

9. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered

(Please attach a copy of each conference abstract)

Month / Year / Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the Institutional Repository *(Yes or No)*
8/2023/ Korea	Damage Class Prediction using Machine Learning Algorithm	The 2023 World Congress on Advances in Structural Engineering and Mechanics (ASEM23), Seoul National University, Seoul, Korea	No	Yes	Yes	Yes

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning
(Please elaborate)

N/A

11. Student(s) Trained
(Please attach a copy of the title page of the thesis)

Name	Degree Registered for	Date of Registration	Date of Thesis Submission / Graduation
	Civil Engineering	9/2022	5/2024

Details
The undergraduate student worked on a FYP project titled *Artificial Neural Network and Civil Engineering*. The project aims to conduct a literature review on the use of AI in different disciplines in civil engineering practices and to apply data-driven methods to structural problems. The student helped to investigate the theoretical background for different machine learning algorithms, and general usage of each algorithm in engineering practices. This is valuable to let the student understand and familiarize himself with the recent developments and applications of AI to the construction industry.

12. Other Impact
(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

N/A

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	Conference Papers	Scholarly Books, Monographs and Chapters	Patents Awarded	Other Research Outputs (please specify)	
No. of outputs arising directly from this research project	1 (under review) 1 (under preparation)	1	0	0	Type	No.
					0	0

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	Reasons
N/A	N/A