Professional paper

IMPORTANCE OF THE 2020 CROATIA EARTHQUAKES GIS-BASED BUILDING USABILITY DATABASE

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Abstract: *The 2020 Petrinja Earthquake caused many negative consequences, but also some positive effects on the future of the disaster risk reduction system in Croatia. One of them was to highlight the importance of the Croatian Centre for Earthquake Engineering and its elements, such as the 2020 Petrinja Earthquake GIS-based Building Usability Database.*
Initially, the database was used only by the Croatian Centre for Earthquake Engineering for internal use during Building Damage and Usability Assessment, as well as for reporting on the status of building damage in the area affected by the disaster, but gradually it proved to be a very valuable source of information for all stakeholders involved in the post-earthquake response and recovery.
This led to the need for a more advanced database, which resulted in the creation of the 2020 Croatia Earthquakes Building Usability Database. This new comprehensive database enabled the continuous tracking of the real-time usability of buildings in the earthquake-affected area in correlation to the reconstruction process and other factors. Not only were the changes entered into the database daily, but the status of each building had to be checked daily as the numerous processes utilized the database as a relevant source of information.
Three years after the 2020 Croatia Earthquakes, the importance of the database is still very high. Therefore, this database can serve as a case study for exploring the possible role of similar databases in the future that increase overall disaster resilience.

Keywords: *Building Damage, Civil Engineering, GIS-based database, Earthquake, Emergency Management*

1. INTRODUCTION

There are still many existing gaps regarding earthquakes and each new earthquake brings out new findings and therefore presents a new opportunity to fill those gaps. Even though earthquakes are geographically limited hazards, the findings are usually globally applicable, as was the case with 2020 Croatia Earthquakes.

One of the key findings after 2020 Croatia Earthquakes was the role and importance of GIS-based databases in response and recovery after disasters, especially earthquakes. This area is not the focus and is generally not sufficiently studied and emphasized in the field of earthquake engineering and emergency management. They have a supporting role to the Building Damage and Usability Assessments, but their potential is much greater, and this has already been proven in past emergencies and studies.

Therefore, it is important to study and report on real-world experiences that confirm the importance of GIS-based databases. The experiences after the 2020 Croatia Earthquakes have been studied and reported in several studies, most notably by Jerković and Škreblin, and this study serves as an extension focusing on the follow-up activities after their studies. The 2020 Croatia Earthquakes GIS-based Building Usability Database can serve as an example of numerous good practices, but also of numerous problems that have occurred and from which the global community can gain new insights or confirm the existing ones.

The 2020 Croatia Earthquakes and the associated GIS-based Building Usability Database can serve as a great example for similar national emergency management systems that have a very low level of earthquake risk mitigation and preparedness. The overall response and recovery after the event illustrate the lack, but also the importance of risk reduction and preparedness, which can greatly facilitate and simplify post-disaster emergency management.

On the other hand, the complex and difficult situation after the 2020 Croatia Earthquakes was mitigated by high-quality “ad hoc” solutions, which included the GIS-based Building Usability Database. The database was essentially created essentially overnight during the first hours after the earthquake and updated again overnight after the 2020 Petrinja Earthquake and its catastrophic consequences. But the database was not only sufficient to fulfil its main purpose, but it also served many other purposes, some of which were not even imagined when it was created.

2. BUILDING USABILITY DATABASE PREVIOUS USE IN THE REPUBLIC OF CROATIA

There was almost no data on buildings in the existing databases of the emergency management system in the Republic of Croatia and there were no specialized building databases that were being used inside the system (Atalić et al., 2019). There were some databases outside the system that were not used by the system, mainly academic and urban planning and permit issuance databases.

A small group of experts regularly pointed out in the 2010s that the building databases were needed to carry out the activities of the emergency management system in all four phases, but without success with the decision-makers (Atalić et al., 2019).

Even historical emergencies in the Republic of Croatia have not raised awareness for the establishment of building databases, not even those that had a direct impact on the buildings. For some of them, even the Building Damage and Usability Assessments, were carried out, but not in a form that is standardized today.

Most notable were the 1996 Ston earthquake and the 2014 Eastern Croatia floods. After the 1996 Ston earthquake, engineers organized and carried out assessments, that were documented and used for reconstruction (Stojan et al., 2000). After 2014 Eastern Croatia floods engineers again carried out

assessments using improvised methodologies and in paper forms with a defined set of data that had to be filled in manually, but were later digitalized using additional human resources, and this database was later used for reconstruction (MPGI, 2015).
Previously mentioned group of experts underwent continuous training and took part in operational activities that enabled them to expand their knowledge and create a theoretical draft of the comprehensive building database and standardized and adapted methodology and forms for Building Damage and Usability Assessments and corresponding database and its specific characteristics (Atalić et al., 2020).
This theoretical knowledge could not be implemented without the support of the decision-makers inside the emergency management system. The lack of awareness and support was present until 2020, when the Zagreb earthquake caused significant damage overnight and the building damage and usability was required.

2.1. 2020 Zagreb Earthquake GIS-based Building Usability Database

After the 2020 Zagreb Earthquake the previously mentioned group of experts was called by the City of Zagreb's Department for urgent situations with the goal of carrying out thousands of Building Damage and Usability Assessments. The experts formed the unofficial platform Croatian Centre for Earthquake Engineering (CCEE) and started the assessments of critical infrastructure.
The group of experts also started preparing the system for Building Damage and Usability Assessments, Figure 1. The paper forms were created and used during the first two days, but meanwhile the digital form creation started in ArcGIS Online with the help of a specialized private company GDi (Šavor Novak et al., 2020).

Figure 1. Rapid education for Building Damage and Usability Assessments (private collection of Croatian Centre for Earthquake Engineering - Intervention Service)

A digital form was created, which was continuously updated according to the feedback, and a form for the citizens' assessment request was also created (Šavor Novak et al., 2020). The collected data from all forms was georeferenced and stored in real time in the free temporary Esri Disaster Server.
The result was the 2020 Zagreb Earthquake GIS-based Building Usability Database, which was an ad hoc solution of several prepared and capable stakeholders. It proved to be highly operational and fulfilled its main purpose of supporting and improving the building damage and usability assessment process.
In addition, due to its digital characteristics it proved to be very valuable for further analyzing and reporting of the buildings and, because of its quality, it was used as a basis for many acts and decisions,

e.g. alternative accommodation, reconstruction process rights and utility bill exemptions (Jerković and Škreblin, 2021).
Based on these needs, access to the database was enabled for several stakeholders, but with a limited level of access according to realistic needs to ensure the security of the data which lacked formal regulation (Atalić et al., 2021).
The database had the potential to evolve and become the central database for many activities in the reconstruction process, but more importantly in the future, including better preparation for future Building Damage and Usability Assessments, (Uroš et al., 2020), Figure 2.

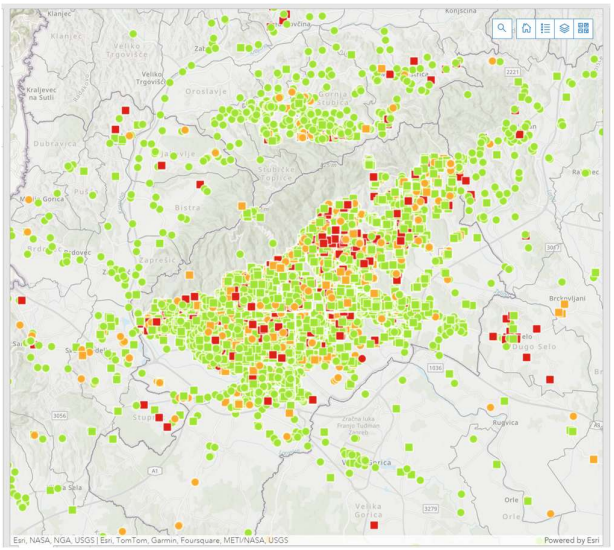

Figure 2. 2020 Zagreb Earthquake GIS-based Building Usability Database (CCEE, 2024)

However, after its initial use, the database was not continuously improved and updated, so it gradually lost its importance and purpose. At the end of 2020, there was an obvious loss of interest, it became clear that the emergency system will not use this opportunity to make significant systematic changes in this area (Atalić et al., 2022).
The database itself was still used for several activities and since it had to be moved from the online infrastructure, it was stored on the infrastructure of the City of Zagreb, as it was mainly responsible for response and recovery activities. As it became less important, the City of Zagreb formed a working group responsible for managing the daily use, but also for determining the future of the database (Šiško et al., 2021).

2.2. 2020 Petrinja Earthquake GIS-based Building Usability Database initial development

In the last days of 2020, the Petrinja Earthquake struck with a significantly higher magnitude than the 2020 Zagreb Earthquake.
Again, there were no prepared procedures as there was no systematic implementation and improvement of lessons learned from the Zagreb earthquake regarding Building Damage and Usability Assessments. So again all assessments had to be improvised, but this time, even without formal and organizational improvements, the CCEE had recent experience that it was able to use. However, the task was more difficult due to the characteristics of the earthquake and the significantly larger area affected. The CCEE, together with partners from the City of Zagreb and GDi, used their experience and repeated the whole process of database creation again.
This database is also based on a similar database created after the 2020 Zagreb earthquake, but in an improved version. The 2020 Petrinja Earthquake GIS-based Building Usability Database, together with

the more mandatory and attributes in general and larger number of surrounding applications, showed numerous improvements over its predecessor (Jerković and Škreblin, 2021), Figure 3.

Figure 3. 2020 Zagreb and Petrinja Earthquakes Building Damage and Usability Assessment Database attributes comparation (Jerković and Škreblin, 2021)

These improvements include the automatic calculation of some fields, the existing layers of people's residences and the official address model, but also the quality control and the process that ensures that the assessments and the corresponding data are checked and, improved if necessary, with particular attention to the accurate addresses (Jerković and Škreblin, 2021).

Although the database showed significant improvements, there were still several problems with the assessments. The problems include: no internet connection on the field (use of manual forms and their subsequent digitalization), merging and systematization of requests from several citizens for the same building, lack of correspondence of addresses (one building has several addresses in the official databases and the owners/tenants do not know which one is relevant) and there were no regulations for access and security of the database (Jerković and Škreblin, 2021).

All these problems are the result of inadequate preparation, just like after the 2020 Zagreb earthquake. Experience can only have a slight impact, but a systematic approach is needed for satisfactory results.

3. 2020 CROATIA EARTQUAKES GIS-BASED BUILDING USABILITY DATABASE

After the aforementioned studies and publications and their results, the database continued to exist and continued to be used daily. The further use, importance and development is also very valuable and is described in the following part of the publication.

3.1. 2020 Petrinja Earthquake GIS-based Building Usability Database further development

After the Building Damage and Usability Assessments in the disaster area and the accompanying quality control had been completed, the Building Damage and Usability Assessments in the wider area affected by the earthquake began. By the end of 2021, the Building Damage and Usability Assessments finally concluded with a total of 50.000, Figure 4.

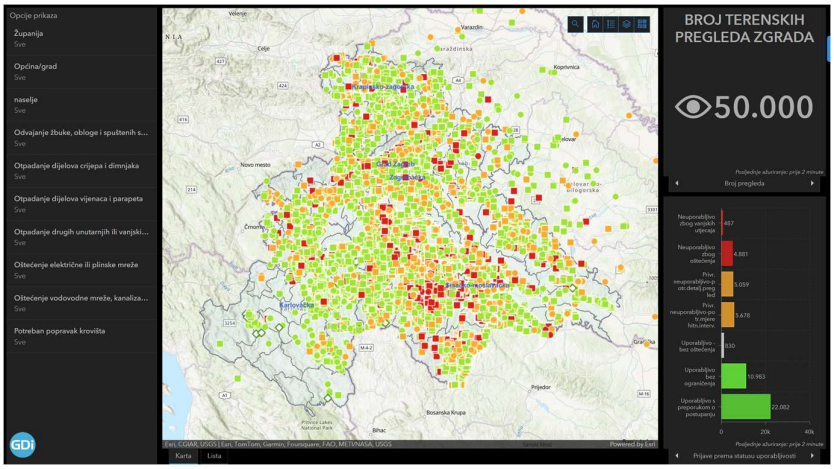

Figure 4. 2020 Petrinja Earthquake GIS-based Building Usability Database (CCEE, 2024)

The database itself was in the same position as it was after the 2020 Zagreb earthquake Building Damage and Usability Assessments were finalized. It was of sufficient quality to fulfil its main purpose, which it did, but it was not able to support other activities within the CCEE, but also outside it. However, it had potential to serve a wider purpose with further development.

Not only the database could not support other activities, but also numerous acts and decisions that were passed from the first days after the earthquake and were based on it (alternative accommodation, donations/humanitarian aid prioritization, reconstruction process rights, utility bill exemptions, bank loans approvals and many others), and all of them involved a lot of pressure and responsibility (Kadić, 2023).

The main problem was the correspondence of the building addresses. More than 80% of the addresses in the database were corrected and verified during the quality control process so they corresponded to the official Croatia building address database, but the process was not finalized because there were not enough volunteers.

However, all other databases that had to be overlapped with the Building Damage and Usability Assessments Database in order to fulfill the obligations from the acts and decisions did not match the official Croatia building address database and, more importantly, there is no unique building identifier. To fulfil the requirements of the acts and decisions regarding the database, individual verification was required for some claims. The individual verification involved several other stakeholders in the process and required additional capacities, both in terms of organization and implementation, which affected the CCEE the most, as the Building Damage and Usability Assessments Database was the focal point because of its quality and importance.

Dozens of individual checks were being carried out daily and in certain situations there were even thousands of individual checks in one day. Nevertheless, some problematic claims could not be checked and verified because of the problems already mentioned.

And at the end of 2021, parallel to the end of Building Damage and Usability Assessments and quality control, a new problem additionally complicated the functionality of the database functionality. The database had to be transferred from the Esri Disaster Server to a permanent infrastructure. This was an extremely challenging process and decisions had to be made during the planning phase.

The first choice was to select the City of Zagreb's server for temporary housing, as it already stored the 2020 Zagreb Earthquake GIS-based Building Usability Database and they offered to take over this database for free as well, as the CCEE and the Faculty of Civil Engineering (University of Zagreb) had no funds for infrastructure.

However, due to this decision, only a selected parts of the entire 2020 Petrinja Earthquake GIS-based Building Usability Database could be transferred to the City of Zagreb infrastructure. The migration from Esri Disaster to the City of Zagreb server was a very complex process and it lasted for days due to the large volume of data and only a selected parts of the entire database were transferred.
Since it was a temporary solution and the database was located on the infrastructure of the City of Zagreb, several activities had to be suspended, mainly quality control and the data improvement, but also all other new data entries and the creation of new layers or sub-databases.
This caused problems because during the checks of individual claims some additional problems with addresses were found (ones that passed through quality control), which required additional capacities for their improvement. However, a bigger problem was the fact that additional capabilities were needed within the database and the reason for this is new activities that are part of the reconstruction process.
During the reconstruction process, all buildings underwent a detailed assessment, in which their usability was changed according to the results of the assessments. Due to the numerous actions and decisions based on the usability of the buildings, the need for real-time usability tracking was crucial.
After consultation with all stakeholders and due to the its quality and relevance it was decided that the Building Usability Database and the CCEE will be responsible for all future usability tracking and updating for the reconstruction process, but also for other recovery processes, mostly related to all acts and decisions.
This decision was confirmed in a legal act on the reconstruction process and the pressure on the CCEE grew. The need for a comprehensive Croatia Earthquakes GIS-based Building Usability Database was immediate and the Zagreb and Petrinja Building Usability Databases had to be overlapped, along with the new data from the reconstruction process.

3.2. 2020 Croatia Earthquakes GIS-based Building Usability Database establishment

As the current database infrastructure only had limited capacity, the CCEE urgently needed to find a new solution. On the positive side, the Ministry of Physical Planning, Construction and State Assets as the government body responsible for reconstruction and related legal acts, was able to provide limited resources in accordance with the legal obligation to maintain real-time usability data.
A quick analysis of the needs and realistic possibilities had to be carried out. After the analysis, a compromise solution was found, and a low-capacity online server was rented. This server would host Croatia Earthquakes' GIS-based Building Usability Database which had to be formed.
During the formation, the accumulated knowledge from two existing databases (Zagreb and Petrinja Earthquake) was used and, more importantly, both databases served as a starting point for the new comprehensive Building Usability Database. Only the most important attributes of the two existing databases were migrated from the City of Zagreb sever.
This reduced the required storage space and therefore the cost of the online server, but there was still a need to manually check the data on the City of Zagreb server when the details of certain assessments were needed. It also meant that it was no longer possible to check and improve the quality of the existing data in both databases as it was not complete.
In addition to the layers of the existing databases, a new layer had to be created to enable the input of the new data connected to usability changes in the reconstruction process. This layer was not limited to just a few of the most important attributes, but included more than a hundred attributes and was fully digitalized and optimized to support detailed assessments.
Along with the database itself, like for the Building Damage and Usability Assessments, a specialized online application form was created. Using the form, engineers can enter the data from the assessment directly into the database without the need to subsequently digitalize the data from the assessments and related official documents, which can instead be generated from within the application and therefore speeding up the process of derailed assessments.

To fully implement the online application form for all interested engineers in the reconstruction process, each of them had to have an official software license to access the database. Each license had to be paid for, as well as the additional server capacity to store all the data from the assessments.
As funds were limited, the decision was made, in communication with the government bodies responsible for reconstruction, to postpone the use of the application form. It was decided that the comprehensive database and all its parts would be stored on the official state server and the funds for the sufficient bundle of licenses would be secured from the government budget.
Until that is realized, all the usability updates were agreed to be done manually monthly by CCEE according to the data provided by bodies responsible for reconstruction.
Owners who did not participate in the official government administrative procedure for reconstruction also had the opportunity to detailly assess and repair their buildings. This gave them the opportunity to change the usability of their buildings. They were also able to submit the documentation to the CCEE, which updated the usability status in the database
Along with the individual checks related to the actions and decisions, the workload related to the Croatia Earthquakes GIS-based Building Usability Database became overwhelming and the CCEE had to hire a private company CrisMa Solutions to take care of the entire workload.
During the reconstruction process, in addition to detailed assessments, construction sites began opening and usability began to change as necessary repairs and retrofits were completed. Since Croatia Earthquakes GIS-based Building Usability Database was the primary database for tracking building usability in real time, new changes had to be made to ensure comprehensive support for the reconstruction process and building usability tracking.
For that purpose, some completely new attributes (type of reconstruction, document type) as well as new values in existing attributes (demolished and reconstructed in usability categories) were added to the database. This even proactively ensured that all future reconstruction and database requirements were covered.
Over time, there was a growing number of entries in the new reconstruction layer in the Building Usability Database, Figure 5. Multiple inputs for the same building were also no exception as the buildings went through different stages of reconstruction. This and the initial inputs from Buildings Damage and Usability Assessments required an expert understanding of the gradation of input types to accurately interpret the building usability category in real time.

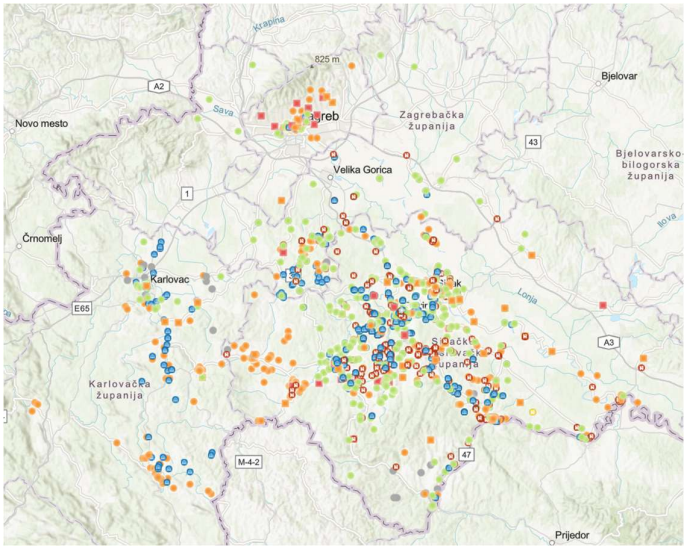

Figure 5. 2020 Croatia Earthquakes GIS-based Building Usability Database Reconstruction Layer (CCEE, 2024)

This required certain level of understanding which only experts from the CCEE and the CrisMa Solutions had. To prevent misinterpretation of the building usability categories CCEE limited access to the database to selected government bodies responsible for reconstruction and instructed them to ask the experts for additional help in interpreting the data.
The restrictions on access to the database had a positive impact on another activity related to the database, and that is ensuring the privacy and security of the database, especially since there were no regulations regarding database security. The value of the database is very high as there are several interested groups (banks, insurances, real estate agencies, construction companies and many others) trying to access the data. Over time, the CCEE has started to create formal regulations, but they could not be adopted until the database is stored on the official and isolated CCEE infrastructure on the official state server.
There were many other issues whose resolution had to wait for the database to be stored on the official state server, including the use of the online application form for the reconstruction process, the overlapping of existing databases/layers, quality control and improvement, the possibility of using license bundles (for numerous users) for which the government provided the funding.
CCEE was granted access to the official state server in January 2023. The official state server is certainly going to allow the database to reach its full potential and solve all the forementioned problems, but also to save considerable additional resources that had to be invested.
This database must become a basis for all future activities of the CCEE, but also for all activities related to buildings in the Republic of Croatia, much wider than just earthquake response and recovery. To ensure this, a proactive and comprehensive approach is also needed.
Some of these additional activities already existed during the 2020 Croatia Earthquake, when the CCEE was not able to integrate its activities (and those of other organizations) into the existing database. These activities include geotechnical hazard assessment, safety corridors assessment and establishment, urgent demolition need assessments and the demolition itself, temporary safety shoring, reconstruction process selection assessments and others.
In addition to the activities in the response and recovery phase, the CCEE also has numerous activities in the prevention and preparedness phases. These activities include hazard mapping, risk assessments, seismic certification, critical infrastructure regular controls and many other activities. All these activities must be included in the comprehensive building database.

4. CONCLUSIONS

The Republic of Croatia was not prepared for earthquakes, and this became evident after the 2020 earthquakes and the subsequent response and recovery efforts. This is the main reason why the entire emergency management system did not respond satisfactorily, especially in terms of coordination and cooperation of all stakeholders.
However, the great human effort and the ability to improvise contributed to the overall positive impact of the systems response on the disaster. One of the examples is also the 2020 Croatia Earthquakes GIS-based Building Usability Database, even though it did not fulfill its full potential.
Therefore, this database should serve as an example for other systems, especially considering all environmental conditions, because there are many other countries and their emergency management systems that are in a similar situation of preparedness and will be in a similar situation when the disaster occurs.
Also, this example has more significance because there are not many other examples of studies in building usability databases in emergency management. It is important that other countries and systems understand and learn from the things that were not done or could have been done better in this situation,

especially regarding importance of a comprehensive and systematically planned approach in the prepared-ness phase, which was missing in this case.
This is also important for the CCEE and the Republic of Croatia. They need to use all their experience and further improve the existing database to reach its full potential and long-term use. This will be especially important in connection and cooperation of all databases related to buildings. The best example of this is the need to introduce a unique building identifier that ensures the possibility of overlapping several independent databases.
All further activities and developments must be accompanied by appropriate studies and all results must be published because of the importance of this example.

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VAŽNOST GIS BAZA PODATAKA O UPORABLJIVOSTI GRAĐEVINA NAKON POTRESA U PETRINJI 2020. GODINE

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Sađetak: *Potres u Petrinji 2020. godine je izazvao mnoge negativne posljedice, ali je imao i pozitivne učinke na budućnost smanjenja rizika od katastrofa u Republici Hrvatskoj. Jedan od njih je bilo i isticanje važnosti Hrvatskog centra za potresno inženjerstvo i njegovih elemenata, kao što je GIS Baza podataka o uporabljivosti građevina nakon potresa u Petrinji 2020. godine.*

U početku je bazu podataka koristio samo Hrvatski centar za potresno inženjerstvo za internu upotrebu prilikom procjena oštećenja i uporabljivosti građevina, kao i za izvješćivanje o stanju oštećenja građevina na području katastrofe, ali je postepeno baza podataka postala vrlo vrijedan izvor informacija za sve dionike uključene u odgovor i oporavak nakon potresa.

To činjenica je izazvala potrebu za naprednijom bazom podataka, što je u konačnici rezultiralo stvaranjem GIS Baze podataka o uporabljivosti građevina nakon potresa u Hrvatskoj 2020. godine. Ova nova sveobuhvatna baza podataka omogućila je kontinuirano praćenje uporabljivosti građevina na potresom pogođenom području u realnom vremenu i u korelaciji s procesom obnove i drugim čimbenicima. Ne samo da su se promjene svakodnevno unosile u bazu podataka, nego se status svake zgrade morao svakodnevno provjeravati jer su brojni procesi koristili bazu podataka kao relevantan izvor informacija.

Tri godine nakon potresa u Hrvatskoj 2020. važnost baze podataka i dalje je velika. Stoga ova baza podataka može poslužiti kao studija slučaja za istraživanje moguće uloge sličnih baza podataka u budućnosti koje povećavaju ukupnu otpornost na katastrofe.

Ključne riječi: *Oštećenja građevina, Građevinarstvo, GIS baze podataka, potres, upravljanje u kriznim situacijama*