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Reinforced Brick Masonry in Urbanization of Rwanda Secondary Cities

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ABSTRACT

To ensure equitable development for all the regions of Rwanda and to limit migration into and prevent congestion of Kigali, the capital city of Rwanda, the Rwandan government has embarked on the development of secondary cities. Consequently, there is the need to provide affordable and safe buildings in the proposed secondary cities. This study investigated the feasibility of using reinforced masonry bricks (RBM) for constructing buildings in the Rwandan secondary city in Muhanga District as an alternative to using reinforced concrete (RC) presently in use in the Kigali based on the availability of clay as the raw material for the production of masonry bricks needed for RBM. Questionnaires were administered and interviews were conducted to establish the level of acceptance of RBM for constructing building in Muhanga. The comparison of the costs of construction building using RBM and RC and the other advantages of RBM over RC for constructing buildings the Rwandan secondary city in Muhanga District are presented.

Keywords: *Clay brick, Reinforced brick masonry, Reinforced concrete, Secondary cities, Strength performance.*

1. INTRODUCTION

Reinforced brick masonry (RBM) has been under use all around the world as one of the most reliable construction methods for low-rise storey buildings, especially thanks to their good resistance to compressive, tensile and shear stresses, and to lateral earthquake loads (Kanamori, 1923; Brzev, 2007). Experience has shown that no efficient development is possible if all resources are concentrated only in the capital and main cities. To ensure equitable development for all the regions of Rwanda, the government has formulated a policy to develop secondary cities to limit migration into Kigali, the capital city of Rwanda and prevent the city congestion (EDPRS II, 2013). Presently in Kigali, the capital of Rwanda, storey buildings are constructed with reinforced concrete (RC), which has made building construction expensive, as cement used for the production of concrete and other cement products for constructed buildings is expensive.

Consequently, there is the need to provide affordable and safe buildings in the proposed secondary cities. Using RBM for building construction could serve as good and cheaper alternative to using RC for building construction for the secondary cities in Rwanda because of the availability of clay, used for the production of masonry bricks, the principal materials for RBM construction. While the RBM technique is under strong concurrence with reinforced concrete construction (RCC) when comparing their strength and durability as key requirements, it may be considered as a more affordable alternative for areas where brick row materials are available. In the context of the continuous rising of building construction cost, especially related to building materials, the selection of the RBM technique should be well analyzed in function of the expected building site. As the steel reinforcement manufacturing industry was growing in Rwanda, the RBM technique can be considered in conventional story buildings, while putting in place and respecting all strategies for environment conservation.

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In this work, the feasibility of using RBM for constructing the buildings of the secondary cities in Rwanda based on the availability of clay as the raw material for the production of the bricks, the principal material for the construction of RBM is presented. Among others, the specific objectives were: to identify the key requirements for a modern city, to review the properties of reinforced brick masonry, and to conduct a structural comparison between Reinforced Brick Masonry and Reinforced Concrete structures with regards to their strength and affordability.

A significant change in the use of RBM came after the 1933 Long Beach earthquake when it was realized that unreinforced structures were susceptible to major damage from earthquakes and that RBM could be used to save lives. Since that time codes were developed that promoted the use of reinforced structures, and reinforced brick masonry construction has been adopted as standard practice for various types of structures in many areas (Hugo, 1933). RBM walls have shown high performance regarding the flexural capacity and ductility which was 5-16 times higher than non-strengthened walls (Triwiyonoa et al., 2015). The quality control of RBM construction is performed by checking the strength of the individual materials, e.g. brick, mortar, and grout prior to or during construction (Technical Notes 17A, 1997). That control has shown an increased resistance to tensile and shear stresses, and this allows better use of brick masonry's inherent compressive strength. Experimental test and numerical analysis showed that the presence of the bars allows control of the cracks phenomenon, keeping the structure in the desired safety condition (Churilov & Dumova-Jovanoska, 2012).

The comparative analysis on reinforced and unreinforced brick masonry walls established the shear strength of 0.23MPa for reinforced masonry and 0.174 MPa for unreinforced masonry respectively (Kumar, 2019). In their experimental study of reinforced brick masonry structures, Sakthivel et al. (2016) demonstrated by relevant test, that the average collapse load of the reinforced brick masonry was 2.63 times more than ordinary brick masonry. Also, a comparative study on prospect of constructing reinforced brick masonry (RBM) structures in Bangladesh, after comparative analysis with unreinforced brick masonry (URM) have confirmed the higher performance of the former, especially regarding the compression, tensile strengths as well as seismic performance (Islam et al., 2016). Finally, the study about comparison of costs for brick and reinforced structures, applied to building up to two floors and span up to 7 m showed that with the use of conventional bricks the cost was reduced at 22% and 62% for external and internal wall respectively (Saheyl, 2013). In Rwanda, the clay brick materials are mostly used for single detached private houses as their strength performance characteristics were still limited (Mbereyaho et al., 2014). Therefore, in the cities, concrete structures were still dominating and with that, the cost of housing has been constantly increasing. There has been different initiatives to promote the brick masonry housing as one of affordable solutions for medium-income earners, and modern brick construction systems have been introduced, in form of multiplexes, Swiss Cube System, etc. for limited building height (Wyss and Dieye, 2017). The increase of urbanization in Rwanda, especially by implementing the secondary cities, currently one of the Rwanda development strategies, would require not only most performing materials, but also economically reasonable to allow an equitable access to the buildings. The use of local materials not only would speedy the implementation, but also make building more affordable (Mbereyaho, 2014). The objective of this study was the assessment of

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RBM structures for story buildings, as well as the comparative analysis between those structures and RC structures in order to establish their application potentials in the ongoing country urbanization.

2. MATERIALS AND METHODS

The study was conducted by reviewing the literature and analyzing the worldwide application of RBM material, visiting the site with purpose to investigate on the local master plan requirements, and assess the level of row material availability, before assessing its performance once applied to construction of a reinforced brick multi-storey building. As a limitation, this study did not check the performance characteristics of individual RBM walls, and it may be an area for further study. But, available data from previous studies could be used as reference.

2.1. Materials

The materials utilized for this study are presented in the following sections.

Clay and clay brick

The clay bricks shown in Fig.1 utilized for the work were prepared and fired at site in Muhanga shown in Fig.1. The wet sieve analysis and Atterberg limit and the Plastic limit tests were conducted on the clay. The compressive strength and water absorption tests were conducted on the bricks.

Steel reinforcing bars

Reinforcement steel bars were added in reinforced concrete structures and reinforced brick masonry structures to strengthen the structures under tensions. Used reinforcement steel were locally manufactured and found in local markets.

Mortar

Bricks are bedded in and jointed with mortar. A good mortar spreads easily, remains plastic while bricks are being laid to provide good bond between bricks and mortar. In reinforced bricks housing a cement mortar is preferable than other type of mortars.

Figure 1. One site of clay and respective manufactured brick

2.2. Methods description

Interviews

The questionnaire was administered and interview was conducted get information on the level of application and acceptance of reinforced brick as a construction material and respective building structure in the targeted area.

Based on the clay availability, Muhanga was selected for this interview, and the population sample of 54 people was selected to participate in the study. This sample was composed of 11 local government authorities, 34 engineers and technicians in the field, and 9 ordinary residents. Their feedback was carefully analyzed, and respective results are presented in section 4.1. The questionnaire enabled the participant to state their preferred types and size of buildings, types of building materials, , knowledge on the performance of local materials used for building construction, and the advantages and disadvantages of Reinforced brick construction in the Muhanga.

Different tests

Different test has been carried out in order to confirm the adequacy of local clay and respective brick. The following are key tests conducted: Atterberg limit test, the Plastic limit test, water absorption test on bricks, wet sieve analysis, and compressive strength test. The standard procedures were used for all mentioned tests and results are presented in section 3.

Cost analysis of the RBM construction

The cost estimation was conducted on the RC and RBM structures, based on design results and, finally a comparative analysis was performed. The selection of the type and level of selected structure was based on the outcomes from the interview, while the selection of foundation type was based on the bearing capacity.

Briefly the cost estimation of the two building structures was performed as per following steps:

○ Selection of the building level and type based on outcomes from survey and interviews.

○ Architectural design of selected building for both RC and RBM structures.

○ Structural design for the two structures with purpose to calculate the materials required, for both concrete and steel reinforcement, as well as the number of bricks per m^3 masonry.

○ Cost estimation using unit cost methods.

3. RESULTS AND DISCUSSION

3.1. Results from interview

The bar chart in Fig.2 shows the building usage types needed in Muhanga. As shown in the figure, all building usage types are needed in Muhanga. The building usage type required most in Muhanga is the residential building with 58% of the total building needs of Muhanga.

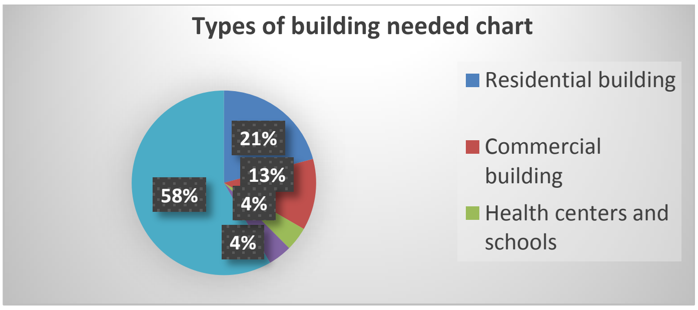

Figure 2. Types of needed building in the area

The bar chart in Fig.3 shows the preferred building storey in Muhanga. It is that 5 to 10 storey buildings are preferred most in Muhanga, with 50% preference compared with 37% and 13% preferences for 1 to 5 and 10 to 5 storey buildings.

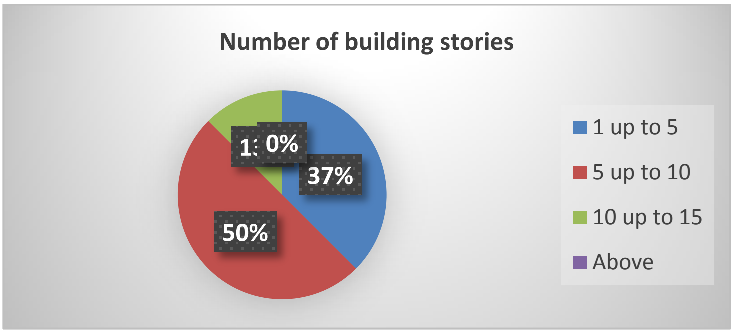

Figure 3. Preferred level of the building in the targeted area

The bar chart in Fig.4 shows the preferred materials for building in Muhanga. The bar chart in Fig.4 shows that buildings constructed with reinforced brick masonry are preferred most in Muhanga with 71% preference, compared with buildings constructed with reinforced concrete and ordinary or unreinforced burnt brick with 21% and 8% preferences respectively. The respondents in Muhanga indicated no preferences for buildings constructed with steel and timber.

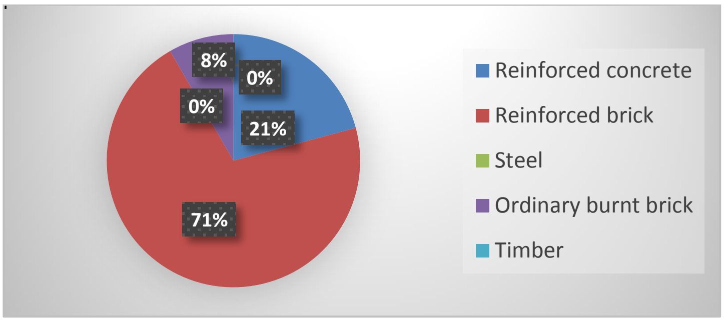

Figure 4. Material preference

Tables 1 and 2 present the advantages and disadvantages of constructing buildings in Muhanga using RBM compared to using RC. As shown in Table 1, constructing buildings in Muhanga using RBM is 75% faster and 70.8% cheaper than constructing building using RC. As shown in Table 2, the most important disadvantage of reinforced brick material in construction were the material mass (90.6%) and the limited number of skilled personnel (87.5%).

As for summary on the interview outcomes, regarding the application of reinforced bricks masonry in the targeted area, it can be concluded that local people understand the advantages in using this material for residential housing. There was a concern related to unit mass of the reinforced bricks material, and the limited skilled personal against its application. For the unit mass, the application of hollow bricks as well as the housing level up to 10 stories may be recommended (Hackmayer et al., 2013). Regarding current skills gap in the field, the situation was changing with increased number of very competent graduates from the relevant field of education and engineers already working in the field.

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Table 1. Advantages of reinforced masonry brick buildings

S/N	Criteria	Percentages (%)
1.	High strength	66.7
2.	Relative low cost	70.8
3.	Speed in construction	75
4.	Aesthetical	83.3

Table 2. Disadvantages of reinforced masonry brick buildings bricks

S/N	Checked factor	Percentages (%)
1.	Skilled personnel	87.5
2.	Mass	91.6
3.	Relative high cost	83.3
4.	Any other (specify)	4.2

3.2. Materials testing Results

3.2.1 Atterberg tests results

The liquid limit test results are presented in table 3.

Table 3. Liquid limit determination

Sample no.	**1**	**2**	**3**	**4**
No. of drops (N)	17	19	21	24
M_C=Mass of empty, clean can+lid (grams)	45.3	45.1	45.1	44
M_{CMS}=Mass of can, lid and moist soil (grams)	62.8	62.9	58.6	56
M_{CDS}=Mass of can, lid and dry soil (grams)	58.4	59.2	55.2	52.7
M_S=Mass of soil solids (grams)	4.4	3.7	3.4	3.3
M_W= Mass of pore water (grams)	13.1	14.1	10.1	8.7
W= water content, w%	**33.6**	**26.2**	**33.7**	**37.9**

The results above show that the liquid limit of this clay was around 40%,

The p**lastic limit test** results are presented in table 4.

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Table 4. Plastic limit determination

Sample no.	**1**	**2**	**3**
M_C=Mass of empty, clean can+lid (grams)	45.4	46	44.1
M_{CMS}=Mass of can, lid and moist soil (grams)	59.1	58.2	62
M_{CDS}=Mass of can, lid and dry soil (grams)	57.3	56.1	59.1
M_S=Mass of soil solids (grams)	1.8	2.1	2.9
M_W= Mass of pore water (grams)	11.9	10.1	15
W= water content, w in%	**15.1**	**20.81**	**19.3**

Finally, the plastic limit is determined by calculating the average water or moisture content of sample, as follows.

Plastic limit= (15.1+20.81+19.3)%/3=**18.4%**

Plasticity index (I_P) = liquid limit (W_L) - Plastic limit (W_p)

I_p=W_L-W_P I_p= 40-18.4 =**21.6%**

The determination process of shrinkage limit is presented in table 5.

Table 5. Shrinkage limit determination

S/N	**Shrinkage Dish No.**	**1**	**2**	**3**
1.	Mass of the container, Wc	62	60.5	59
2.	Mass of container+ Wet soil pat in grm, Wws	108.7	107.3	106.52
3.	Mass of wet soil pat, W_1=Wws-Wc	46.7	46.8	47.52
4.	Mass of container+ Dry soil pat in grm, Wds	99.26	98	97.4
5.	Mass of oven dry soil pat, W_2	37.26	37.5	38.4
6.	Mass of water in grm, Ww=W_1-W_2	9.44	9.3	9.12
7.	Moisture content (%), W=(Ww/W_2)*100	25.33	24.8	23.75
8.	Mass of mercury filling the shrinkage dish W_3	274.28	274.28	274.28
9.	Density of mercury	13.53	13.53	13.53
10.	Volume of wet soil pat (V_1) in cm^3	3.45	3.46	3.5
11.	Volume of dry pat (V_2) in cm^3	2.75	2.77	2.84

Water content of soil, mass of dry soil volume of wet and dry soil is the average of the three results from table 17 above,

Water content (W) = (25.33+24.8+23.75)/3=24.6%

Mass of dry soil (W_2) = (37.26+37.5+38.4)/3=37.72 grm

Volume of wet soil (V_1) = (3.45+3.46+3.5)/3 =3.47 cm^3

Volume of dry soil (V_2) = (2.75+2.77+2.84)/3=2.78 cm^3

Shrinkage limit%, Wsl = (24.6%-((3.47-2.78)/37.72)*1)*100 = 22.77%

Shrinkage ratio, R =37.72/1*2.78=13.57

3.2.2. Water absorption test result

A brick with water absorption of less than 20% provides better resistance to damage by freezing. The water absorption by bricks increases with increase in pores. Table 6 presents the determination of brick water absorption.

Table 6. Brick water absorption test determination

Number of bricks	Weight of bricks before (M_1)	Weight of bricks after (M_2)
1	1701.1	1932.5
2	1633.6	1859.5
3	1769.6	2005.1

The above results showing 13.57% absorption confirm that the brick was good in quality as it is less than 20%.

3.2.3. Sieve analysis test results

Table 7 below presents the result of sieve analysis test and the respective chart is given in Fig 5.

Table 7. Sieve analysis results

IS sieve size (mm)	Weight retained in each sieve (gm)	Percentage retained on each sieve	Cumulative% retained on each sieve	% Finer
2.36	23.8	3.5	3.5	96.5
1.18	41.7	6.1	9.6	90.4
0.600	91.3	13.5	23.1	76.9
0.425	115.2	17	40.1	59.9
0.300	112.4	16.6	56.7	43.3
0.150	201.1	29.6	86.3	13.7
0.075	91.7	13.5	99.8	0.2
Pan	1.5	0.2	100	0

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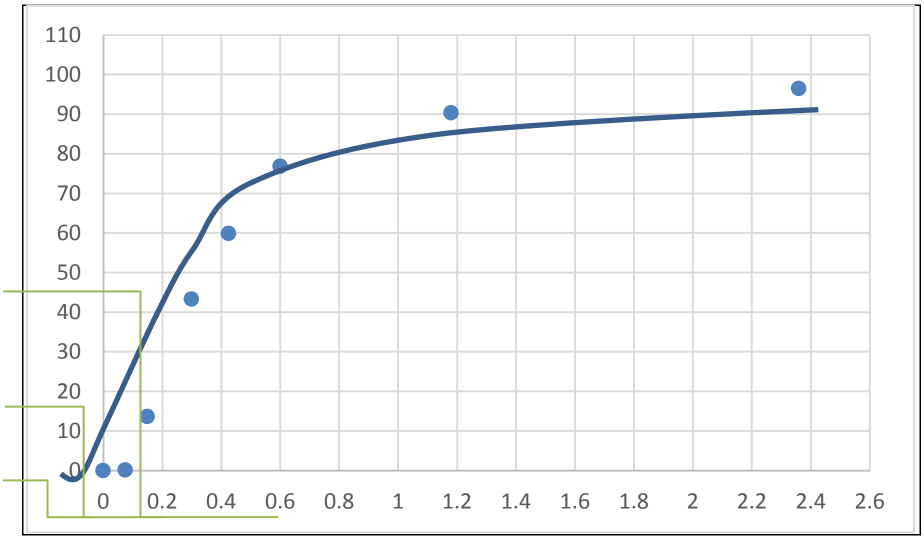

Figure 5. Wet sieve analysis

As conclusion about soil test results, it was established that in Muhanga there is a lot of clay. The wet sieve analysis test shows that the type of clay found there is silt clay. Finally, the Atterberg limit test shows that the liquid, plastic and shrinkage of clay found in Muhanga has property for making a good brick used in reinforced brick construction.

3.2.4. Compressive strength test results

Table 8 presents the results from compression test of different type of brick.

Table 8. Compression test results

S/N	Type of brick	Load (KN)	Length (L) (cm)	Width (W) (cm)	Height (H) (cm)	Strength (MPa)
1.	Brick form low performing clay	119.67	19.2	9	4.7	6.83
2.	Muhanga Brick	241.685	20.4	9.5	6.7	12.41
3.	Ruliba Brick	150.154	20.5	5.3	9.67	13.82

From the table above, it can be seen that the compression strength for the clay brick from the targeted area was 12.41 MPa. This result was in line with standards and other previous study results. Here it can be noted that even the low strength of 6.83MPa, still offers possibility of the application for simple housing (Mbereyaho et al., 2014). On the other side, Muhanga bricks showed even better performance, and its use in RBM will increase that performance and therefore extend its application to middle story buildings.

After getting the positive feedback from respondents regarding the acceptability of RBM in local construction, and key clay bricks strength results, it was relevant to assess the product affordability.

3.2.5. Results on cost analysis of the RBM construction

As stated earlier in section 2, the cost estimation was conducted on the RC and RBM structure, based on design results and, finally a comparative analysis was performed. Based on the outcomes from the interview, a five story building with two structures, different by materials has been used for this analysis. The conducted soil mechanics test results, showed that the bearing capacity was 230 kPa which was admissible for the given structure. The consideration of this bearing capacity in foundation design established that the isolated footing supported by ring beams was the best option for the proposed building structure.

The perspective views of the two structures are given under Fig.6 and Fig.7 respectively for Reinforced Brick and Reinforced Concrete Building.

Figure 6. Reinforced brick building **Figure 7.** Reinforced concrete building

The fig.8 shows the top view or plan of proposed building structure.

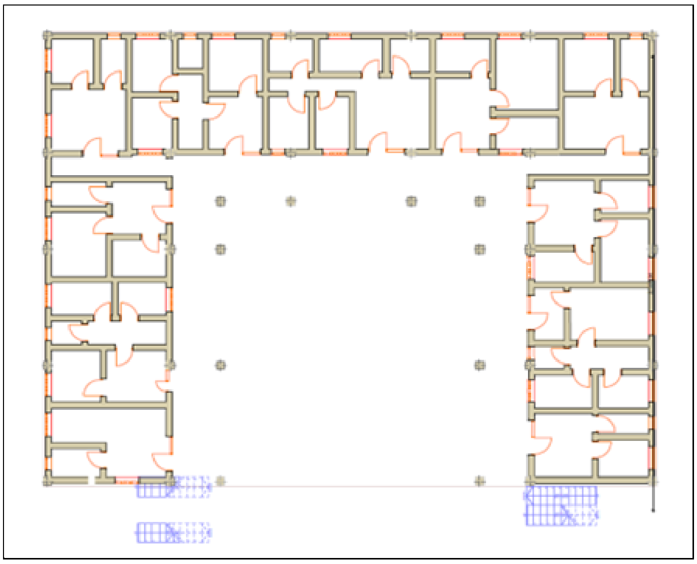

Figure 8. Top view of proposed building

Design considerations and materials referred to ACI 530/ASCE/TMS 402 [16].

After the structures design, the cost estimation of reinforced brick house and reinforced concrete house were conducted using the unit cost methods. The total estimated cost for the reinforced brick building structure was 1,066,167,788 Rwf. The cost estimation for reinforced concrete house is established at 1,296,471,076 Rwf. This shows a cost benefit of around 17.8% with the application of RBM in construction. This result goes in line with some earlier published results (Islam et al., 2016; Saheyl et al., 2013). The RBM structure can be used in all Rwanda areas, and be an answer not only for the affordable housing but also for housing in earthquake zone of the country (Triwiyonoa et al., 2015).

4. CONCLUSION

The general objective of the study was to establish the acceptability level of RBM in local construction, while appreciating its performance, in order to establish its potentials for housing promotion in Rwanda secondary cities. The adopted methodology comprised of clay site identification, determination of clay properties and soil bearing capacity, brick compressive strength test, design of RBM and RC residential building structures as well as their respective cost estimation.

The study confirmed that clay was still available in abundance, especially in the targeted secondary city area of Muhanga, and this clay met standards requirements for good bricks that can be used in RBM housing. The compressive strength tests confirmed the adequacy of using the targeted clay brick in RBM masonry. The cost estimation of both the structures showed that the building cost for RBM housing was 17.8% less than the cost of RC housing.

The study results showed that RBM structure can be used in any city in the country where clay was available, as a strong and affordable solution, especially for middle rise buildings. The influence of soil bearing capacity in selecting the building importance level may be considered as one of potential further studies. Also, while the study promotes the use of RBM in construction, a study related to the environment conservation of clay sites would be another important research scope.

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Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this research work.

Availability of data and material

The authors are willing to share the data and material according to relevant needs.

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