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RESEARCH

# Cost–benefit analysis of building information modeling implementation in construction projects: evidence from Iran

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**Abstract**

Construction projects account for a large percentage of national resources, but they are typically finished at a cost and time beyond the initial estimates. Building information modeling (BIM) helps coordinate and integrate design and construction efforts to achieve the ultimate benefit needed to satisfy all the stakeholders. Despite the reported benefits of BIM, the implementation of such a new technology initially entails costs and barriers that sometimes delay the benefits achieved from their use. BIM also casts suspicion on whether they are useful, thereby reducing its adoption rate. This study aims to evaluate the benefits of implementing BIM functions compared to the cost of its implementation. The results include a cost–benefit analysis (CBA) for three construction projects in Iran by conducting semi-structured interviews. Finally, despite all the limitations and shortcomings, the achieved benefits outweigh the incurred costs, and BIM implementation in these three construction projects was beneficial. One of the innovations of this study is the use of cost–benefit analysis in evaluating the benefits of BIM, which is tangible and quantitative.

**Keywords** Construction projects · Building information modeling · Cost · Benefit analysis · BIM implementation

## 1 Introduction

In recent decades, the construction industry has met numerous challenges, such as lower productivity rates and disappointing returns on investment than other industries. This can result from gradual increases in labor costs, unforeseen costs due to the lack of coordination among stakeholders, and time-consuming changes in managing projects [41]. Excessive cost in construction projects, as one of the reasons for the inefficiency of the construction industry is a common issue that affects project performance. Iranian projects are no exception to this issue. This is also the case in many developing countries, such as Pakistan, Vietnam, Nigeria, Ghana, and Kuwait [9]. In Iran, one of the developing countries, the construction industry experienced a steady decline in value-added, eliminating its former advantage over other sectors of the economy [8]. The situation of sustainable construction in Some developing countries in Southeast Asia including Malaysia, Singapore, Indonesia, Thailand, Vietnam, Laos, Cambodia, Brunei, Burma, and the Philippines is still in its infancy. The lack of awareness, training, and inefficient procurement systems are major obstacles to sustainable construction [38].

Building information modeling (BIM) is a technological concept that has been recently incorporated into project management and construction literature as one of the recent advances in this field. It has also been introduced as an emerging technology and process in the architecture, engineering, and construction (AEC) industry [21] while revolutionizing the AEC industry [42]. BIM transforms traditional project execution practices into more robust and visualized efforts using inherent technologies and concepts [11]. BIM is the process of generating and managing building information over its lifecycle,however, in the beginning, BIM is a common source of information and communication between the entire building design and implementation team. This

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early information integration increases coordination, reduces errors and waste, and ultimately improves work quality [22].

Furthermore, the integration of information through BIM changes the nature of existing and new building operations [17]. When investigating and predicting the side effects of a design solution, BIM-based approaches are much more effective and efficient than traditional ones [16]. The purpose of BIM is to promote collaboration between organizations and various AEC professionals to improve the productivity and quality of building design, construction, and maintenance [23]. Moreover, there are some advantages, such as more significant benefits, more accurate documentation, reduced rework, and reduced project implementation time [29]. The studies show that in small projects, this technology slightly increases costs. Still, on a large scale, it is significantly cost-effective based on time saved with more efficient project operation [7]. Some studies argue that BIM's use increases the costs of the project design phase, but it can also reduce costs in the construction phase and ultimately reduce the total project construction costs [24]. Taheripour et al. [43, 45] show that the adoption status of BIM in Iran is unfavorable. Tai et al. [46] listed major BIM adoption challenges as lack of financial support, unfamiliarity and improper encounter with the BIM concept, inadequate knowledge of BIM advantages, and lack of government support. In a similar approach, Babatunde and Ekundayo [5] investigated existing barriers against implementing BIM into undergraduate curricula at universities. They have listed insufficient government support and leadership, faculty training costs, and a lack of experienced faculty to teach BIM courses as the main obstacles. Another research has stated that in higher education institutes researchers can motivate the instructors to adopt BIM and introduce its collaborative benefits in the construction industry [27].

Poirier et al. [36] concluded that improved labor productivity was a key benefit of BIM and prefabrication under the BIM model showed a productivity increase between 75 and 240% after all aspects of the contractor's participation were quantified based on comparisons with the areas of the project that did not use the BIM model. Nath et al. [33] examined two case studies in South Korea and showed that a BIM-based design effectively reduces construction industry losses by 4.3–15.2%. Won et al. [48] showed a productivity improvement of about 36% based on the time length BIM was used and 38% for the entire project construction time. Ning et al. [34] found that this tool improves design productivity by as much as 265% and reduces the required capital by 4.5% in the power generation unit compared to human-based design. Mesaros and Mandicak (2017) introduced the greatest advantage of using BIM technology as the reduced cost of managing construction projects.

McGraw-Hill Construction [30] stated that BIM adoption in North America had increased by more than 40% from 28% in 2007 within 5 years. In a similar report, McGraw-Hill Construction [29] showed that the BIM adoption rate among European AEC/FM firms in 2010 was only 36%, and for South Korean AEC/FM firms, 58% in 2012. In 2014, 51% of all New Zealand and Australian users used BIM on about a third of their construction projects [31]. More recently, National BIM has reported that 54% of U.K. architects, BIM managers, and project managers respondents were engaged actively with BIM, 42% were only familiar (no active engagement) with BIM, and only 4% had no clue about what BIM is [25].

However, in some countries with little experience in BIM implementation, the project stakeholders, especially in the private sector, usually have a low motivation to implement BIM and view BIM only as an expensive deception [24]. There are reasons for slow BIM implementation in the construction sector in the planning and scheduling phase [19]. Despite the growing acceptance of BIM's benefits, there is little research on measuring the costs and benefits of BIM to assess the financial impact of investing in BIM at the corporate level [35]. Even the research conducted in this area has reported a large-scale return on investment rate, as they are conducted in different countries where different parameters define the costs and benefits of BIM; moreover, the BIM implementation level in each of these studies is different [4]. Therefore, measuring the costs and benefits of BIM in each country offers a quantified estimate of how each country responds to BIM measures. Research on BIM in Iran is mainly concerned with introducing the benefits of BIM, while a study that has measured the costs and benefits of BIM simultaneously is less frequent. Therefore, further research quantifying BIM in Iran provides valuable evidence, documentation, and helpful information for construction industry management in Iran and other countries. In this study, an attempt was made to obtain the costs and benefits of using BIM in three Iranian construction projects to answer the following questions:

1. What is the maturity state of BIM implementation in these three projects?
2. What were the benefits of the BIM functions used in these projects?
3. What was the impact of the BIM implementation on the gained benefits?
4. What were the costs and benefits of implementing BIM?
5. Ultimately, what was the return on investment in these three projects?

In the following section, a literature review on the featured projects is used to present the research methodology described, and the research findings are presented herein, followed by a summary (conclusion) and some suggestions for future research.

## 2 Literature review

Building information modeling leads to a wide range of benefits in complex projects that organizations rely on to move towards its adoption [10]. "The potential benefits associated with BIM implementation (improving data accuracy and project cost-saving) were found to be key initiators in triggering SMOs' interest in adopting BIM" [13]. However, in developing countries, BIM implementation is hampered by barriers such as not investing in emerging technology and not abandoning traditional work habits [2]. "The high cost of BIM implementation is a major bottleneck for SMEs" [37]. Ayinla and Adamu [3] have also shown various limitations such as cost as factors in creating a digital divide in the BIM technology adoption. Babatunde et al. [6] selected four architecture, engineering, and construction (AEC) firms, that drivers used BIM to carry out construction projects in Nigeria. Babatunde et al. [6] presented 23 drivers or goals that motivate AEC companies to use BIM. The top six include: (1) keeping innovation competitive, (2) saving time, (3) better communication, (4) accuracy in construction sequencing and clash detection, (5) a more efficient design process and better design quality, and (6) less pressure to please the client and a desire not to have to worry so much about pressure from competitors. These findings are slightly different from previous studies that found government pressure as one of the primary drivers of BIM adoption. As a result, some BIM benefits and functions in developing countries, such as Iran were identified, to encourage a greater intention to use BIM. A substantial body of research in the academic and industrial fields has investigated the functions of BIM. Hoseinzadeh (2016) provided a list of BIM functions on which the present research is grounded. In this list, 19 functions derived from the BIM implementation (10 design-phase functions and nine construction-phase functions) are presented in Table 1.

**Table 1** BIM functions at the design and construction phases [15]

| Row | Functions at the design phase | Functions at the construction phase |
|---|---|---|
| 1 | Identify and analysis of design options | Development of work breakdown structure |
| 2 | Environmental, energy, and sustainability analysis | Construction visualization and scheduling |
| 3 | Constructability analysis | Procurement planning |
| 4 | Engage with non-specialist stakeholders during the design phase | A better understanding of the scope and complexity of tasks |
| 5 | Facilitate the design and drawing process | Change management |
| 6 | Coordination between different areas | Construction inspection and control |
| 7 | Cost estimation | As-built modeling |
| 8 | Producing construction documents and supplying quantities | Documentation |
| 9 | Help in choosing contractors | Interactions between stakeholders and project members |
| 10 | Shop drawing preparation | |

By reviewing the literature and projects on the benefits, risks, and challenges of BIM based on available information from a project in Georgia involving a hotel and parking use, which utilized BIM. Azhar et al. [4] concluded that applying this concept resulted in savings of $600,000 by avoiding interference and preventing delays. Also, 1143 h were saved during the project implementation. Another approach to estimating BIM savings was completed by determining the BIM return on investment in 10 BIM-led projects. This method showed the ROI value varying from 140 to 39,900%. The main reason for the scattered ROI range in these projects was that each project had a different range of BIM functions. Also, the reported statistics only calculated the saved direct costs, which means the ROI can be much higher. Lu et al. [24] conducted quantitative research on two rental housing projects in Hong Kong, where one project used BIM and the other project did not. The cost–benefit analysis (CBA) concluded that a slight increase in the design effort using BIM was not only offset by subsequent savings in the construction phase but also led to savings in the overall project costs. Therefore, the CBA justifies encouraging the widespread adoption of BIM in the construction industry. According to Lu et al. [24], in their comparison of two multi-story public housing apartment projects (one built with BIM and one built without BIM), the BIM implementation increased the costs of the design phase by more than 46%. Still, it saved about 6.92% or 490.86 HKD ($63.34 in today's U.S. dollars) per square meter of the construction costs. This study is probably the first to articulate the interactive relationship of BIM's costs/benefits at a project's design and building stages. This study's findings will be used to justify the promotion of wider BIM adoption in the AEC industry as a means of alleviating its problems such as low productivity, backwardness, silo thinking, fragmentation, and discontinuity.

After completing a CBA (which adds all costs, including the BIM implementation costs) in the construction of the University of Alaska-Anchorage's sports arena, McConnell and Wang [28] concluded that using BIM would have allowed the completion of the project 11 days earlier and saved $1.35 million or 1.5% of the total project budget. Walasek and Barszcz [47] also researched on analyzing the BIM adoption rate and its ROI. They explored data such as personnel costs, staff training costs, maintenance costs, and other costs of the Malta House project as Poland's first project using BIM on a large scale. They found the design costs to be higher for companies working with BIM. Although the ROI is positive, the design element is an obstacle; long-term savings should encourage implementation. Therefore, they emphasized the benefits of collaboration by utilizing "web-based multi-discipline collaboration platforms". The remote platforms, which have become so popular during the COVID-19 pandemic, are used to get agreement on modifications and extract information as needed from a secure data repository that allows all participants to keep updated on changes and plans when needed. In another study by Shin et al. [39], the CBA of BIM was performed at a railway site in South Korea by examining seven non-BIM projects where 12 errors were identified during the design phase, which could have been prevented if BIM had been used. The projected cost of deploying BIM in both the design and construction phases for the seven projects was estimated at a very conservative $116,348 based on estimates from eight engineering firms, labor costs, and assuming that BIM would be used throughout the project and not be dropped before a more accurate analysis can be made. A more realistic estimate includes a 10% margin of error in which the use of BIM for all seven projects was estimated to cost $127.983. The total cost required to correct the errors in the seven projects in South Korea was $166.486. The errors represent problems that could have been avoided and fixed early enough not to inflict this type of fiscal damage if BIM had been used,thus, the $166,486 represents the savings that BIM could have offered. Shin et al. [39] also calculated the cost of delays based on construction time losses of 1, 2, and 3 months with liquidated damage estimated at $2498 (1.5%), $4994.6 (3.0%), and $7491.9 (4.5%), respectively. Thus, the benefit–cost ratio is estimated as 1.32 with a 1-month delay, 1.34 with a 2-month delay, and 1.36 with a 3-month delay. A study by Abdel-Hamid and Abdel-haleem [1] found that the variance between planned costs and actual costs was reduced from 12 to 5% when 5D BIM was used instead of traditional methods. Therefore, accurate cost estimation and clash detection are useful results of 5D BIM. A cost–benefit analysis (CBA) of the investment value of using BIM and terrestrial laser scanning (TLS) was conducted for 12 case studies by a single organization by Kim et al. [20]. The results showed that the use of these two methods has higher initial investment costs, but has benefits such as reducing manpower and project time. For example, in case study project number 1, the work that was done in 30 days by 6 people can be done by 4 people in 15 days using BIM and TLS, and in the same project, 1392 h of time savings and 50,851 KRW (equivalent to the reduction rate 72.5%) was obtained. The study by Sompolgrunk and Banihashemi [40] provides a comprehensive systematic review of mainstream studies on factors influencing BIM ROI published from 2000 to 2020. Reported BIM ROI ranged widely from − 83.3 to 39,900%. A total of five returning factors, i.e., schedule and compliance reduction, productivity improvement, information reduction request, rework reduction, and change order reduction were identified as the most commonly reported factors affecting BIM ROI.

Several researchers have tried to investigate the importance and benefits of BIM in Iran. Hosseini et al. [14] performed a survey of 44 construction companies, mainly small ones with less than 50 employees, actively involved in Iran's construction market. They concluded that Iran's construction industry is still premature in adopting BIM for their projects. They showed that less than a third of the companies they collected their questionnaires from were only using some BIM features, more than 50% did not have any exposure to BIM, and the rest had no plan for near-future BIM adoption. They also stated in their later research that only 14% of surveyed companies had used BIM in more than five projects. Marefat et al. [26] assessed the important barriers to implementing BIM to improve project safety. They distributed a questionnaire among 36 different project parties (clients, consultants, and contractors) to verify their questionnaire's integrity in catching and recording the relevant factors for Iran. Most recently, Khanzadi et al. [18], using a two-round Delphi study and an advanced Fuzzy-AHP approach, prioritized BIM key performance indicators (KPI) for Iran's construction industry. They showed that quality improvement, sustainable construction, and construction cost reduction are the most important indicators among different KPIs.

As noted in the preceding examples, research measuring the costs and benefits derived from BIM has been conducted in different countries, where different factors affect the costs and benefits of using BIM. As mentioned in the previous examples, research has been conducted to measure the costs and benefits of BIM in different countries, where various factors affect the costs and benefits of BIM implementation. These researches have reported the level of cost and time savings of projects that are in different intervals and the profit rate has been reported in large scales and different fields. A substantial body of research, including some authors who have published articles about BIM in Iran, has qualitatively focused on BIM's benefits. Those researchers have very limited analyses of the costs and benefits of implementing BIM in Iran's construction industry projects in a quantitative and in-the-field practical approach. Perhaps the results of this research, while raising awareness, will help different investors and stakeholders of construction projects according to the real field data from case studies to better understand the BIM in the real environment and Iran's operating context.

## 3 Research methodology

Before starting the research process, a decision had to be made to study one or more cases for this research. For example, if the case study is part of a community and studies a particular subject in-depth in a particular case, using a single-case study is more appropriate; however, if a comparison of case studies leads to a better understanding, a multi-case study is adopted. This paper compares the findings of BIM implementation in several construction projects; thus, a multi-case study is used.

The research population in Iran is highly focused on construction projects. The criteria for selecting the projects were to incorporate BIM in the projects with enough floor area under construction to evaluate BIM implementation costs and benefits. The selected three projects had a floor area of over 190,000 $m^2$; thus, each project had a floor area large enough to justify the cost and time involved in quantifying the costs and benefits of BIM implementation. Another criterion for the project selection was that a single BIM executing company was used in all three projects. Thus, the data collection and the BIM implementation process were based on three separate areas that are all similar enough to allow for project comparison in the study. After extensive review, a BIM implementing company was chosen based on its different experiences with various construction companies as clients, consultants, designers, or even contractors. In these projects, the BIM team represented a group of academically educated people in construction management at top domestic and foreign universities. The fields of interest were civil engineering, architecture, mechanics, and management. The BIM team had to be familiar with the BIM process and technique under international training. Since its formation, the executive BIM team has worked closely with a Canadian company to ensure the team follows the standard BIM procedures already established in Canada, the USA, and the U.K. Because this company has had relatively good BIM implementation experiences, the company was asked to introduce some of the projects they were currently implementing BIM and define what made their research goals consistent with each case study's BIM model objectives. Thus, three case projects were identified for the present study through the BIM implementing company, as described in Table 2.

After selecting the three case projects described in Table 2, the steps in this research were:

**Step 1—BIM analysis of components maturity and implementation:** first, by conducting the semi-structured interviews, the extent of the BIM applicant company's familiarity with the main aspects of BIM implementation in the projects (in terms of technology, organization, and process) was identified. The BIM participants in all three projects are a component of the project, contracted with the BIM implementing company. The technology aspect's maturity is the availability of hardware and software requirements and how the model is clear and usable in the organization. The organization aspect's maturity refers to the extent of revision in the organizational structure for managing the projects based on BIM, the extent to which stakeholders are involved in the BIM implementation process, and the extent to which individuals in the organization are interested in the use of BIM. The process aspect of maturity also reflects the degree of clarity in the roles and responsibilities of those who adopt BIM in an organization and the readiness of a work plan to apply this concept in the organization [12]. The interviewees included the most knowledgeable people in the required fields of study. They had to be familiar with the concept of BIM and its functional areas and benefits. The interviewees also had to have had some experience in the BIM implementation process, including the roles described in Table 3. Snowball sampling was used to select individuals. As such, after the interviews, they were asked to introduce another person with knowledge of the field and study. Similarly, other interviewees were also identified. Snowball sampling was used because could not identify the researchers to identify informants with the three projects. Informants involved in the process of recording and tracking the costs of BIM implementation. After interviewing the members of the BIM applicant company, they were asked to qualitatively score the BIM implementation maturity in the company in which they are working, considering the three aspects of technology, organization, and process, ranging from 0 to 5 (5 = very good, 4 = good, 3 = moderate, 2 = poor, 1 = very poor, and 0 = no maturity). For example, a score of 5 in the technology aspect means that the company has a very good technical infrastructure (hardware, software) to implement BIM. Then, the average score of the individuals was considered in the final score.

**Step 2—BIM benefits analysis:** at this stage, by identifying and reviewing the project documentation, the functions of each project gained through BIM implementation were identified. In the next stage, the semi-structured interviews were conducted with the same people who were interviewed in the previous phase as described in the previous step; they were asked to qualitatively score the benefit of each function gained in the project. In the scoring, they were asked to use a Likert-type scale by rating each project benefit from 0 to 5 (5 = very good, 4 = good, 3 = moderate, 2 = poor, 1 = very poor, and 0 = no benefit). For example, a score of 3 on identifying and analyzing the design options means that the company achieved a moderate benefit. These scores are merely the opinions of the interviewees, which were qualitatively done. Finally, after collecting the field data in this section, the interviewees' average score on each of the functions in each project was identified as the function's benefits. The list of reviewed functions is presented in Table 1.

**Table 2** Introduction of case studies based on projects in Iran

| Type of project | Delivery system | BIM applicant | Time of using BIM | BIM applications |
|---|---|---|---|---|
| Residential town | Engineering procurement Construction (EPC) | Contractor | After concreting the foundation and the first-floor ceiling | 3D modeling, clash detection, and elimination, and providing shop drawings |
| Residential complex | Design Bid Build (DBB) | Consultant | From the beginning of the design phase | 3D modeling, clash detection and elimination, energy analysis, providing shop drawings, material quantity take-off and estimation, project coordination |
| Hospital | Design Bid Build (DBB) | Contractor | While finishing the digging operation | Project procurement and logistics, 3D and 4D modeling, workshop and structural supplying, schedule monitoring, and control |

**Table 3** Specifications of Iran project's research participants in three case studies

| Project type | Individual roles | No. of interviewees |
|---|---|---|
| Residential town | BIM coordinator, technical team leader, project control team, project manager, and the utility and installation designer | 5 |
| Residential complex | BIM coordinator, head of the project design department, the client project manager, consultant and designer, and the client's representative | 5 |
| Hospital | BIM coordinator, contractor's Q.C. team leader, the client's planning manager, the project manager on the contractor side, and the head of the contractor project control department | 5 |

**Step 3—Cost–benefit analysis:** the costs associated with the BIM implementation and the benefits of BIM implementation in each project were calculated as a percentage of the total cost of implementing one square meter of a project. Notably, this analysis had to deal with a confidential contract price. Therefore, the BIM implementation costs and the contract price between the BIM implementing company and the BIM applicant were quantitatively obtained. Because no defined guidelines were available for quantitatively calculating the benefits of BIM implementation, the quantitative measurement was a little time-consuming in the projects that used BIM for the first time. Thus, the figures related to the benefits were obtained by interviewing project experts informed of all the processes. In other words, from those interviewed in the previous steps, those who had more information and involvement in providing data related to the costs and benefits of BIM were selected. In the residential town project with the EPC system, samples with the BIM coordinator and project control team positions were interviewed. In the residential complex and hospital projects, which have been implemented with the Design Bid Build system, respectively samples with the positions of BIM coordinator and head of project design department (in the residential complex project), BIM coordinator, and head of the contractor project control department (in the hospital project) were interviewed. To calculate the benefits of BIM implementation, they were first asked to list the project items associated with reducing the time or cost of BIM implementation. The experts first addressed items that could be quantified to some extent, such as the cost of renting overhead cranes planned as (a), because they were leased earlier. That cost was compared to the cost of cranes that required less time on the project (b) and was, therefore, lower than (a). Then, the cost savings from the partially quantified items were summed up, and the sum was calculated as a percentage of implementing one square meter of the project. There were also some items associated with decreased time. For example, the reduction of time for some activities was avoided to prevent repeating work. The experts based their estimates solely on their expertise and work experience in the project under study. In other words, they expressed cost savings related to time reduction caused by a lower number of workers and working days needed to perform certain activities) as a percentage of the cost needed to implement one square meter of the project.

Finally, the cost savings from the partially quantified items and items where the resulting cost benefits were expressed by judgment as a percentage of the cost of implementing one square meter were separately summed up in the design and construction phases. The total benefit of BIM implementation in these projects was obtained from the sum of benefits in both phases. However, the concept of return on investment (ROI) was also used to evaluate the BIM investment in these projects. The equation for calculating the ROI was expressed as (Giel and Issa, 2013):

$$\frac{\text{Benifits of BIM imp.} - \text{Costs of BIM imp.}}{\text{Costs of BIM imp.}} \times 100 = \text{ROI of BIM imp.} \tag{1}$$

This equation calculated the projects' ROI to a certain level of progress in all three projects to make comparisons at an acceptable level, meaning that a certain percentage of progress was made in all three projects. This is because as the project progresses, the ROI may change; hence, the cost and benefit calculations are based on the lowest progress percentage throughout all three projects. Notably, Figs. 3 and 4 were plotted using the cost and benefit figures of BIM implementation, which are interpreted in Sect. 4. The purpose of using these figures was to determine whether the benefits of BIM implementation outweigh the implementation costs, and if so, how much benefit was received in each project.

**Step 4—Validation of findings:** to ensure the data's validity and obtained results, the data were collected based on a predetermined protocol. The data from all interviews were recorded simultaneously as the interview and were analyzed after the session. After extracting the interview data, the findings were shared with the people who were fully involved in the work and well acquainted with the whole work process. The sentences and results that were inconsistent or ambiguous were re-examined by BIM experts and were agreed upon. After this stage, the findings were made available to several project managers, and their validity was ensured. In other words, the project manager did the final validation of the findings in the residential town project. The client project manager managed the residential complex project, and the client's planning manager did the hospital project.

# 4 Findings

## 4.1 Projects BIM maturity in terms of the main aspects of BIM implementation

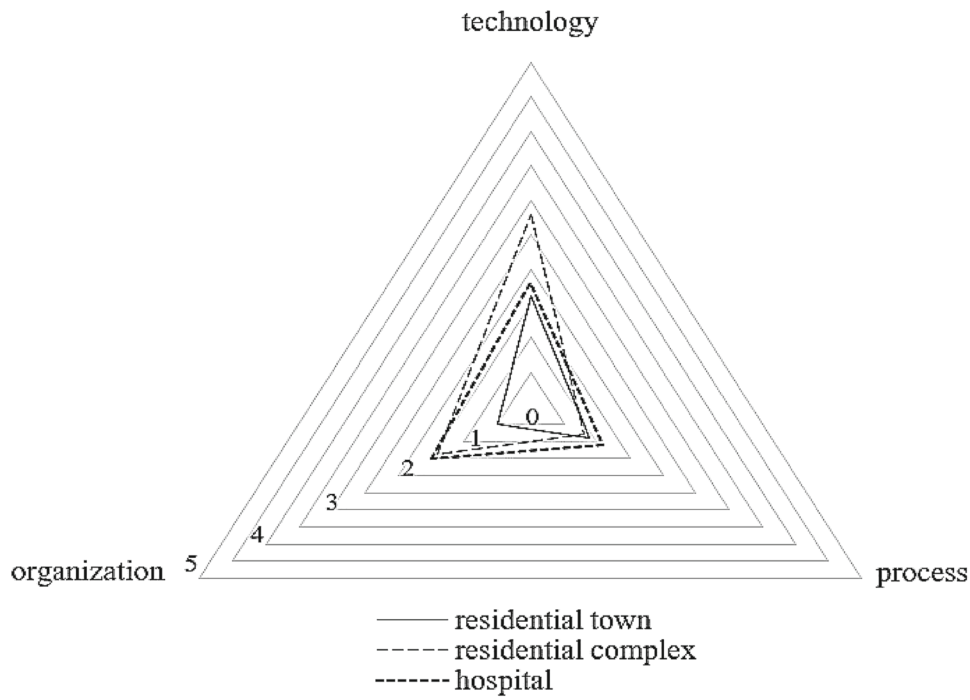
The purpose of this part of the study is to determine how maturity affects the number of benefits each project receives through BIM implementation, and ultimately, how BIM-built maturity affects the ROI. In other words, this section measures each company's readiness and how it affects the technical, organizational, and process infrastructure outputs after BIM implementation. The outputs in this study are the benefits of implementing BIM functions qualitatively and the ROI quantitatively. The opinions' average score was obtained as the score for each aspect, as shown in Fig. 1 for all three projects. Figure 1 shows the residential complex project as more mature than the hospital project, and the hospital project is more mature than the residential town project. Also, a very low level of the whole form is filled by the BIM applicant company's maturity regarding the main aspects of BIM implementation. In this way, the technical, organizational, and process components are available to interested parties (collaborators, leadership, and project participants). Now when they were asked to score each item from 0 (lowest maturity) to 5 (higher maturity), the average score of the components in each aspect was considered as the final score of the aspect, and the average score of all three aspects was calculated as the BIM applicant maturity for the project. In the residential complex, hospital, and residential town projects, scores 1.6, 1.4, and 1 were obtained, all far from the best score of 5. These scores are, however, equivalent to the maximum maturity. Perhaps one of the reasons for this finding is that although about a decade has passed since the emergence of BIM in Iran, technological change in Iran is a bit slow, and resistance to change is due to getting used to traditional construction methods.

## 4.2 Benefits of BIM functions in case studies of three construction projects in Iran

According to the interviews conducted with the BIM experts of each project, the projected benefits of BIM, as used in the three projects built in Iran, were created to score BIM functions' benefits. Figure 2 shows these benefits in the order obtained. Here, the residential town and residential complex projects benefited from the design phase functions, while the hospital project largely benefited from the construction phase functions. This is mainly because, in the hospital project, BIM was implemented after the design phase mainly to use 4D modeling after concluding the contract with the BIM implementing company. Based on Fig. 2, the residential complex project has more benefits than the hospital project, and the hospital project also has more benefits than the residential town project. Perhaps one of the reasons for the higher benefit is the higher maturity of the BIM applicant. It means the greater the maturity of BIM implementation, the more justification was given to applicant companies for using BIM, which is subject to further review.

Moreover, the higher the maturity of BIM implementation in this study, the more benefits were gained through the BIM implementation. On the other hand, perhaps the short history of BIM implementation in Iran is not without any effect since

**Fig. 1** BIM applicant maturity in three major aspects of BIM implementation



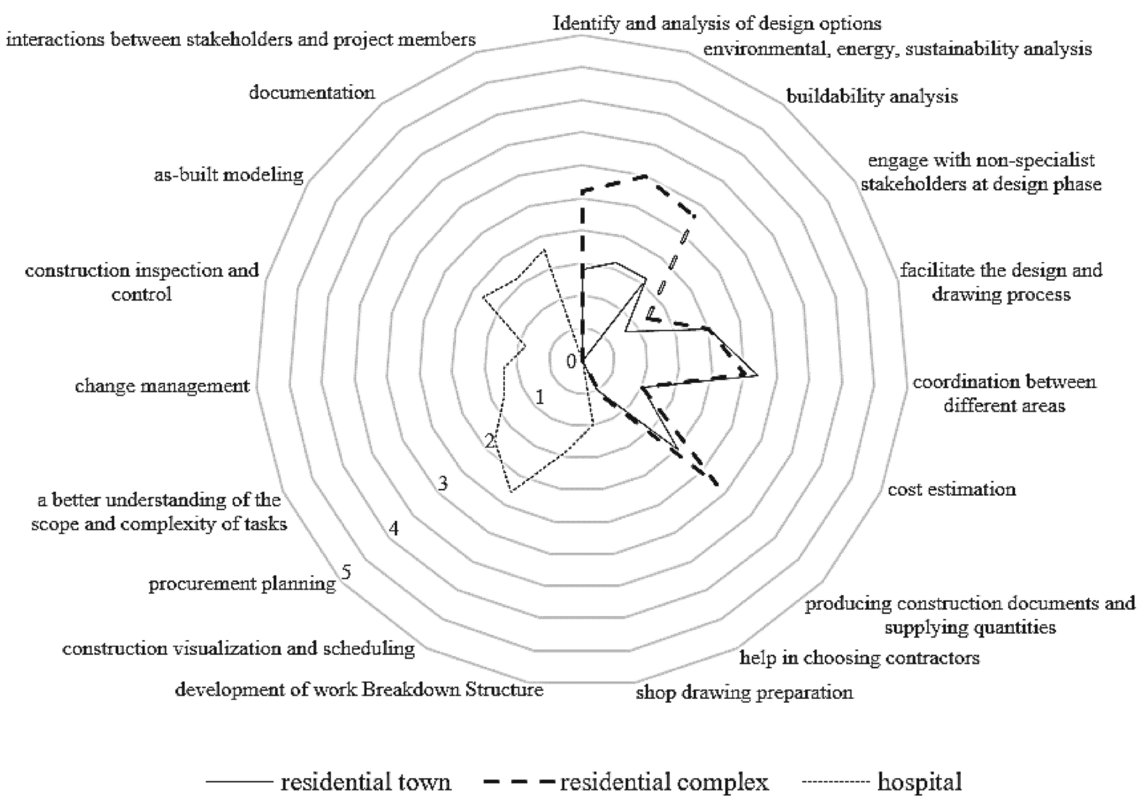




**Fig. 2** Benefits of implementing BIM functions in projects

benefits were gained from implementing the BIM functions. The benefit level could have been much higher, but BIM did have a positive effect on Iran.

It seems that one of the reasons that a relatively small surface area of Fig. 2 is filled is that BIM was first used in these projects, and the project components were not attuned to the concept and process of working with the BIM. An example of the lack of familiarity with BIM in Iran is the fact that residential town and residential complex projects only used part of the BIM design phase functions; moreover, the hospital project only used part of the construction phase functions, and the hospital project's use of the design phase functions was much smaller than that expected from most BIM projects. Therefore, the higher the use of BIM functions in these projects, the more benefits can be gained.

### 4.3 Cost–benefit analysis of BIM implementation in projects

All the figures related to the costs and benefits of BIM implementation are presented as percentages due to the confidentiality of the contract price. For example, you consider x to be the cost of constructing and implementing one square meter of the project in the residential town contract. In that case, the contract price between the BIM implementing company and the EPC contractor (as BIM applicant) is $0.24\%x$, 70% of which is the cost of 3D modeling, and 30% is related to the cost of eliminating the interventions. For the reasons stated in the research methodology section, the benefits of BIM were not precisely quantified. Therefore, the interviewees who were the experts in these projects were asked to incorporate the benefits of BIM implementation into two design and construction sector benefits. They expressed their opinion on the total benefits of the two design and construction phases as a percentage of the same amount of $x$ to provide a common basis for the comparisons' implementation costs. The benefits of the design sector in this project include reduced time and a lower cost for architects to review, print, and communicate the drawings. Another benefit was the reduced delay penalties. The construction sector's benefits included reduced rework costs, reduced delay penalties, and the reduced cost of purchasing and renting construction equipment. The total benefit of BIM implementation was obtained by averaging expert opinions scores as $4.5\%x$; 20% in the design sector, and 80% in the construction sector.

The data on the costs and benefits of BIM implementation in the residential complex project were also obtained, as stated in the residential town project. In this project, if considering the cost of implementing one square meter of the project, the contract price between the BIM implementing company and the project consultant (as a BIM applicant) is $0.3\%y$, 75% of which is the cost of 3D modeling, and 25% is related to the cost of eliminating interventions. The benefits of implementing BIM in this project also fall into two categories design and construction benefits. The benefits of the design sector in this project include the reduced time and cost of architects for reviewing, printing, and communicating the maps, reduced time in general, and the human resources needed to estimate the costs and reduced penalties of contract duration extension. The construction sector's benefits include the reduced cost of modifications and reworks, reduced penalties for extending the contract duration, reduced working hours of engineers and workers, reduced wages, reduced cost of renting and building the equipment and reduced cost of materials due to faster ordering. In this project, while interviewing the experts, they were asked to express their opinion on BIM benefits in terms of a percentage of the price of implementing one square meter of the project. By averaging the scores of expert opinions, the total benefit of BIM implementation was obtained as $4.7\%y$, 35% of which was the benefits of the design sector, and 65% referred to benefits applied to the construction sector.

In the hospital project, which was similar to the residential town and residential complex projects, if the cost of implementing one square meter of the project is equal to $z$, the price of the contract between the BIM implementing company and the project contractor (as BIM applicant) is $0.22\%z$, 15% of which is related to 3D modeling costs and 85% to 4D modeling. The total costs of 3D and 4D modeling constitute all the costs of BIM implementation in this project. The benefits of BIM implementation in this project fall into two categories: design and construction sector benefits. However, because BIM was introduced into the project at the end of the design phase, the design sector benefits constitute a very small percentage of the benefits related to BIM implementation. Besides, according to the experts' average opinion in this project, only 10% of the benefits are related to this sector. The construction sector's benefits include the reduced cost of reworks, reduced time and cost of making changes, reduced cost and time of renting construction equipment, and reduced workers. By averaging the scores of expert opinions, the total benefit of BIM implementation was obtained as $2.7\%z$, 10% of which was the benefits of the design sector and 90% of the construction sector. Table 4 lists the information on the costs and benefits of BIM implementation in these projects, along with the ROI.

Figure 3 shows the costs and benefits of BIM implementation in all three projects according to the information in Table 4 in chronological order (costs in descending part and benefits in the chart's ascending part). The points in Fig. 3 are organized as follows. In the first two projects, the 3D modeling costs and then the costs of eliminating the intervention are spent, and in the third project, the 3D modeling costs and the 4D modeling costs are spent. In the benefits section, once the costs are spent without any additional costs spent on the

**Table 4** Costs and benefits of BIM implementation in case studies based on ROI

| Type of project | Costs of BIM implementation | | | Benefits of BIM implementation | | | ROI (%) |
|---|---|---|---|---|---|---|---|
| Residential town | 3D modeling (70%) | Clash detection (30%) | Total cost (100%) | Design (20%) | Construction (80%) | Total benefits (100%) | 1775% |
| | 0/168%$x$ | 0/072%$x$ | 0/24%$x$ | 0/9%$x$ | 3/6%$x$ | 4/5%$x$ | |
| Residential complex | 3D modeling (75%) | clash detection (25%) | Total cost (100%) | Design (35%) | Construction (65%) | Total benefits (100%) | 1466% |
| | 0/225%$y$ | 0/075%$y$ | 0/3%$y$ | 1/65%$y$ | 3/05%$y$ | 4/7%$y$ | |
| Hospital | 3D modeling (15%) | 4D modeling (85%) | Total cost (100%) | Design (10%) | Construction (90%) | Total benefits (100%) | 1172% |
| | 0/033%$z$ | 0/187%$z$ | 0/22%$z$ | 0/28%$z$ | 2/52%$z$ | 2/8%$z$ | |

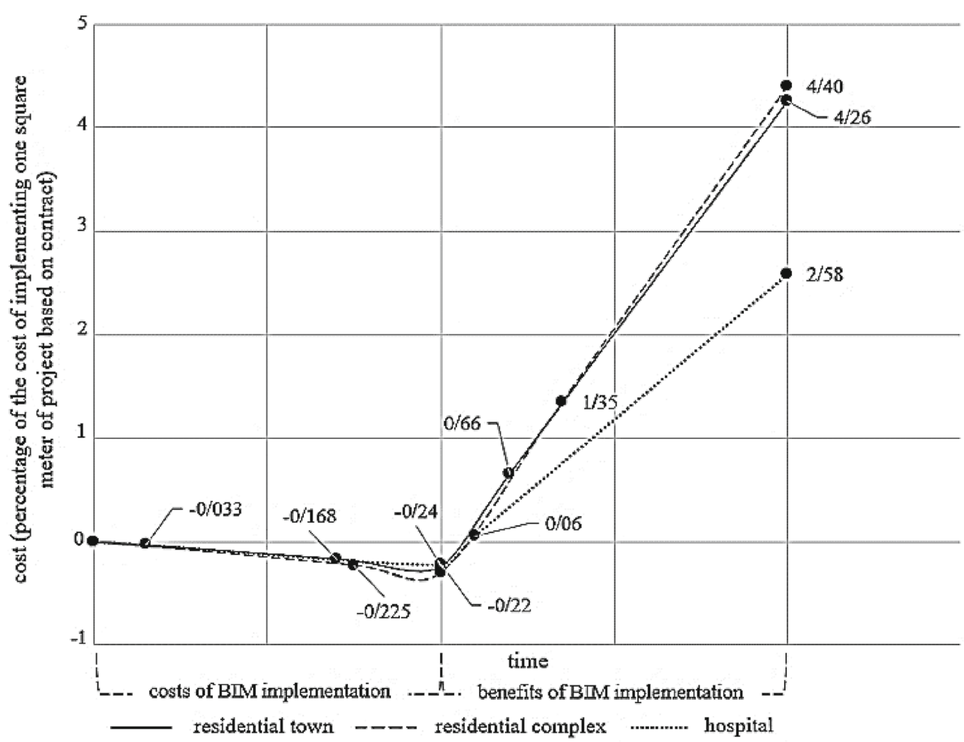



**Fig. 3** Benefits of implementing BIM functions in projects

BIM implementation, the design sector benefits are obtained, followed by the construction sector benefits.

The first conclusion from Fig. 1 is that in all three projects, the benefits outweigh the BIM implementation costs, indicating that although the projects were progressing at the time of data collection and all the benefits of using the BIM were not achieved, the positive ROI means that the higher rates are expected to be achieved once the projects are completed. The figures of 1775%, 1466%, and 1172% as the ROIs in these cases represent the minimum levels that have been obtained from the projects so far.

Another point is that the ROI in the residential town project obtained at 1775% is higher than that of the residential complex project which achieved a rate of 1466%, and both ROIs are higher than the hospital project obtained at 1172%. Likewise, as shown in Fig. 3, the residential town project chart and the residential complex project chart have higher slopes representing greater BIM implementation benefits than the hospital project chart. However, the accurate and final ROI comparison in these projects cannot be made by relying solely on the charts' slope. Regardless of the certainty that the ROI is positive, the chart's slope may break and change later. Another issue is that the order of ROI calculations in these three projects is not from higher to lower, as is the case in Sect. 4.1 concerning the maturity of BIM implementation in the three projects. In addition to the infrastructure available for BIM implementation that determines the maturity of BIM implementation, many other factors affect the ROI in these projects, which calls for further research in this area.

Figure 4 is another representation of the figures in Table 4. The first conclusion is that the length of the benefit bars in all three projects exceeds the length of the cost bars, which demonstrates the usefulness of BIM regardless of each value. However, most benefits of BIM implementation were achieved in the construction phase. That was because the planning and design with BIM in the design phase and the increased costs were done to obtain the results at later times and during the construction phase, to which a lot of time and costs were allocated for implementing the project.

Perhaps one reason that the benefit-to-cost ratio in the hospital project was less than the other two projects is that BIM was introduced into the project at the end of the design phase and the beginning of the construction phase. The project also incorporated the design phase functions to a very limited extent, which had some effect in achieving the results—even though it was not as great as it could have been given more experience and training. In other words, about 70–80% of the costs in the construction phase were adopted by design and planning phase decisions, and perhaps the project deprivation or lack of complete design phase functions is one of the reasons for achieving an ROI that was less than that of the other two projects.

## 5 Discussion and conclusion

The present study aimed to assess whether BIM implementation in three construction projects in Iran can be fruitful. In other words, if the answer is yes, there will be incentives for investors and other stakeholders to use this technology in their projects at the end of this study. For this reason, after selecting three construction projects in Iran, which were the first to use BIM in their projects, a cost–benefit analysis was performed using various tools such as calculating the ROI and plotting the cost–benefit shown in Figs. 3 and 4. Finally, the most important results of this study were obtained as follows:

According to the results of some studies mentioned in the literature review, such as the study by W. Lu et al. [24], the use of BIM was shown to increase the costs of the design sector by 46%. Also, in the research by Polish researchers Walasek and Barszcz [47] on the Malta House project, the use of BIM in this project resulted in increased costs in many sectors, including personnel costs and staff training costs, and hardware procurement costs. In the three case projects, the use of BIM initially adds to the costs exceeding what is spent on the project when not using BIM. It sometimes discourages and lowers the motivation to implement the project components. This can happen when BIM is perceived as a formal and non-practical method, especially for projects with a long implementation time, where having a long-term orientation is important to achieving the ultimate benefits of BIM. An extended timeline (long-term orientation) was a huge factor in the three Iranian projects under study. Considering the cost-benefits in Fig. 3, the chart shows a downward and then upward trend. Moreover, despite the positive ROI in the three projects (1775% for the residential town, 1466% for the residential complex, and 1172% for the hospital), compared with the figures obtained from the ROI in other similar projects as verified in the literature, there is still a great gap. For example, Azhar [4] reported the ROI in 10 projects varying from 140 to 39,900%, with an average ROI of 9480% in the ten projects. ROIs of the three Iranian projects were obtained when many of the BIM functions were not implemented. The familiarity level of all three organizations with BIM was relatively low (1.3 out of 5), indicating the presence of stagnant conditions in the Iranian construction industry and the lack of a suitable context for implementing the BIM concept; however, the use of BIM in three construction projects in Iran was promising because, in these three Iranian case studies featured herein, all the benefits were not achieved until the measurements were made. Thus, this minimum amount of benefit from the BIM implementation in these projects can be increased over time, which is an encouraging result that incentivizes Iran's inefficient construction industry. It seems that the short history of BIM technology in Iran, which has emerged in the construction industry in less than a decade, has a positive effect—even on the first 3-project case in Iran featured in this paper.

As Oesterreich and Teuteberg [35] noted in their research, the net benefit from BIM in the first year was relatively low. Some of the reasons were the costs associated with their 2018 project's start-up activities, including the cost of necessary technical supplies and the cost of training the staff on using BIM for the first time. If the mentioned organizations use BIM in their future projects, they may obtain higher profit rates. This is because after using the technology the first time, it becomes easier to proceed as the challenges of controlling the many costs and learning to use BIM to solve problems are conquered.

In summary, data obtained from case studies illustrate the positive impact of BIM use in certain projects, even in challenging situations. Acceptable results were obtained despite all the limitations, including the lack of standards and guidelines at the governmental and organizational level, and the absence of a national BIM database. Nevertheless, these results presented herein are far from what has been

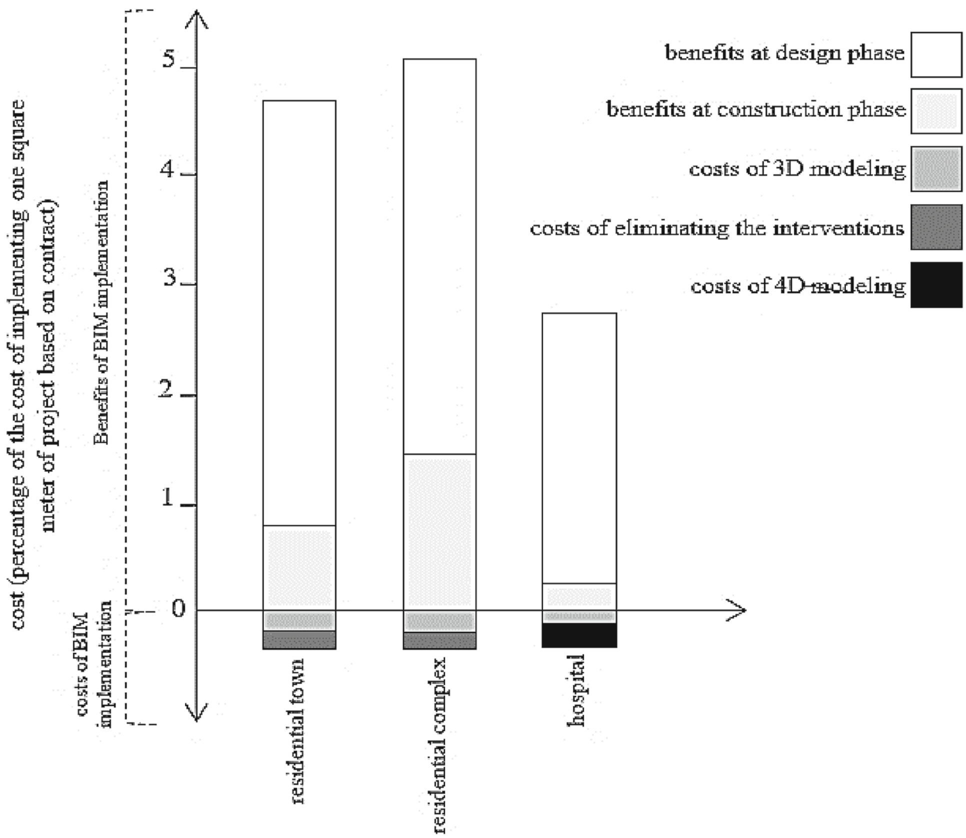



**Fig. 4** Bar chart of costs and benefits of BIM implementation in projects. All figures are presented in terms of a percentage of the cost of implementing one square meter of the project based on the contract

achieved in some countries, but they can be used as an incentive for organizations to use BIM to achieve higher profit rates. Among the strengths of the article, we can mention the real applicability of BIM the actual implementation of BIM, and the presentation of real data related to the profitability of the three studied projects. Findings that are not from theory but from reality. However, the limitation in the number of BIM projects and the lack of coherent and classified data have been part of the limitations of this study, which will pave the way for additional research based on more accurate and complete data in the future. Another limitation of the research was that the findings can only be generalized to projects with a similar scale to the three studied projects in the construction industry of Iran and cannot be applied to other industries in Iran or the construction industry of other countries due to the unique characteristics of each. Among the different characteristics of Iran's construction industry compared to the industries of other countries, it is possible to point to the higher or lower rate of BIM experts as a kind of example of human resources, the difference in being more technologically receptive, etc.

Researchers in the R&D departments of companies or academic researchers can use the findings of this research to apply this methodology to compare the costs and benefits of BIM in ongoing projects and whether or not it is useful in the work scale. Also, companies, especially project-oriented organizations that have projects with similar conditions to the three projects under consideration, that are planning to implement BIM for the first time, and face resistance from their employees can use the research findings to convince them to face fewer obstacles.

## 6 Suggestions for future study

Based on the experiences gained from the study of existing research and examining the three case studies in the above research, some shortcomings were identified, which can be used as suggestions for future research. These suggestions are:

1. Develop guidelines for measuring the costs and benefits of BIM implementation in the project environment and research ways to quantify and measure BIM benefits.
2. Investigate cost–benefit analyses in larger communities and statistical populations to perform more detailed analyses and to compare selected groups together. Comparisons of cost–benefit analyses in construction projects with other civil and industrial projects also represent an neglecting area.

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## Declarations

**Competing interests** The authors declare no competing interests.

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