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Panels made from recycled tire-application of linear model to test the tensile force

Andjelko Crnoja
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Abstract

Background: Number of used tires is increasing every day and the accumulation of such waste is a serious problem in terms of environmental protection and in terms of delay and deposition (End-of-Life Tires, 2019). Over the last twenty years the study of new ways to use products from recycled tires has been intensified. When developing new products, it is important to investigate how certain properties of the materials used change. According to the available literature, different variants of material composition and processing approaches have been investigated (Kowalska, Chmielewski, Guleira & Dutta, 2017; Zaoiai, Makani, Tafraoui & Benmerioul, 2015).

Objectives: The aim of this work, based on the evaluation of an experiment using a mathematical model, is to determine the required structure of the material. The possibility and correctness of using the linear model was determined.

Methods/Approach: The experiment was conducted to check the magnitude of the deformation depending on the stress. Results: Based on the obtained results, the accuracy of the applied linear model and the influence of individual factors on the results of the experiment were evaluated. Conclusions: Mathematical linear model estimation refers to the determination of quantitative parameters in the structure of a material. If the required deformation is defined or acceptable, other material parameters can be determined with some accuracy.

Keywords: mechanical properties, linear model, rubber crumb, tensile, deformation

Paper type: Research article,

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Introduction

Technological development, increased production and economic growth increase the demand for the production of building materials. On the other hand, increasing the
amount of waste is a big problem in all countries of the world. The authors (Farrag, Ibrahim & Elalfy, 2017) cited Egypt as an example and explain how large financial resources are spent on the reconstruction of landfills in that country. They also indicate the reasons why used car tires can become a serious environmental problem and adversely affect human health.

Tire volumes in developed countries are decreasing, while in less developed countries, this waste is accumulating. An example is South Africa, with an estimated 800 million consumed tires and 1-2 billion in Mexico (End-of-LifeTires, 2008). Some studies show a direct relationship between the worn tire and the occurrence of certain serious human diseases (Marsili, Coppola, Bianchi & Fossi, 2014; Beausoleil, Price & Muller, 2009; Swedish Chemicals Inspecorate, 2006; Cardno Chem Risk, 2013; Bocca, Forte, Petrucci, Costantini & Izzo, 2009; IARC, 1983). Long studies and tests show how these particles separate from the wheels when using and driving on roads and penetrate the human body (Panko, Kreider, McAtee & Marwood, 2010; McAtee, Kreider, Panko & Finley, 2012).

In 2007, the European Commission issued a Directive (European Commission, 2007) aimed at making the dismantling and decommissioning of used tiers and their components environmentally friendly. Currently, the author, available literature (Guleira & Dutta, 2012; Kowalska, Chmielewski, Guleira & Dutta, 2017; Zaoiai, Makani, Tafraoui & Benmerioul, 2015) discusses using of recycled rubber as admixtures of mixtures of concrete, gypsum, asphalt, geotechnical applications, etc. All of these studies suggest an additive, not a finished and applicable product.

The author wants to show that recycled rubber can be used and applied to industrial and residential buildings in such a way that it actively participates in the protection of the structure and interior or exterior in different types of insulation, primarily in the protection against noise. Using samples from the recycled tires as independent material is intended to show that such type of material is applicable. It is known that the material needs to be treated with certain liquids that will neutralize odours, prevent erosion in terms of the formation of micro and nano particles that can enter the body, all in order to obtain a specific product.

Recently, a lot of time and resources have been spent on solving these problems. In addition to environmental protection, the disposal of such waste is a significant result of the production of new products as a result of recycling in various fields.

The world's major economies have shown that it is profitable to recycle rubber and with a well-thought-out strategy, new jobs can be created. The situation in Croatia and neighboring countries is such that there are few car tire processors. The leading company is "Gumiimpex", which in several of its plants recycles and manufactures certain products. However, this production is minimal and insufficient to take over rubber-based waste in Croatia and its surroundings. A large part is exported as rubber granules (semi-finished product, raw material) for large processors.
Certain studies have shown that products can be put into mass consumption in construction, and the design of such products can stimulate production, regional development and provide multiple positive effects on environmental protection. Tests show that the market has the potential to be used to open new plants to produce new products.

This study aims to evaluate the mechanical properties of recycled rubber using a statistical linear model. The properties were evaluated based on an experiment conducted on an axial tensile tester.

**Methodology**

The experiment was performed on calibrated devices. The reason for this is the control and the accuracy of measurements. The devices were properly selected and used. Certain deviations or measurement errors are taken into account and accounted for in the final result. The testing equipment was easy to use. The recycled rubber samples were made in accordance with HRN EN ISO 527-4: 2008 "Determination of the tensile properties of plastic materials" and were tested on AXIS FB 20K axial equipment as shown in Figure 1.

![Figure 1](image-url)

**Figure 1**

Equipment for conducting the experiment

*Source: Author’s illustration*

When using this device, it is possible to apply force to the sample manually and hydraulically. When high forces are applied, the load is exerted by the hydraulic pump and smaller loads are produced manually. In the case of the experiment the force was applied manually at regular intervals corresponding to the amount of strain. For easier monitoring, it is recommended that the value of the applied force acting on the sample be an integer. Water-based pressure cutting technology was used in the preparation and production of the samples. Depending on the size of the sample, the
operation can be performed by cutting with a jet or with finished tools for this purpose. The water jet cutting device can be seen in Figure 2.

![Figure 2](https://example.com/figure2.jpg)

**Figure 2**

Water jet sampling equipment

*Source: Author's illustration*

The sketch and sample dimensions are visible in Figure 3. The sketch has been prepared in accordance with the applicable standard while the cutting is performed on a device operated by a computer. The contours of the cuts visible on the monitor. Two identical samples were prepared, which were cut at the base at the same time. The cut should be nice and without any damage to the sample, which can weaken the sample on the test area. Such sample would be destroyed and the measurement would be defective. A sample sketch can be seen in Figure 2.

![Figure 3](https://example.com/figure3.jpg)

**Figure 3**

Sample scheme according to standard

*Source: Author’s illustration*

In the experiment we used samples of different thickness, the specific gravity of the binder content. The thickness of the samples varied and ranged from 10 to 20 mm. Specific mass of the samples ranged from 585 to 916 kg / m³. The specification of
the samples is shown in Table 1. The samples also show a thickness of 10 mm, with a specific mass of 585-600 kg / m³ not even made.

Table 1
Technical characteristics of test samples

<table>
<thead>
<tr>
<th>Granulometric composition</th>
<th>№ sample</th>
<th>№ sample</th>
<th>№ sample</th>
<th>Thickness of the sample, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>700-750 kg/m³</td>
<td>1</td>
<td>4</td>
<td>*</td>
<td>10</td>
</tr>
<tr>
<td>900-916 kg/m³</td>
<td>13</td>
<td>16</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>585-600 kg/m³</td>
<td>22</td>
<td>25</td>
<td>19</td>
<td>20</td>
</tr>
</tbody>
</table>

Note: * - no sample was created in this category (valid for the indicated specific mass)

Source: Author

The samples were made with the same particle size distribution of 0.5-2.0 mm (Gumiimpex, 2020) with different specific gravities from 585 kg/m³ to 916 kg/m³ (Table 1), different thicknesses of 10, 15 to 20 mm and different weights of polyurethane adhesive binder (Table 2).

Table 2
Quantity of binder in samples / material

<table>
<thead>
<tr>
<th>№ sample</th>
<th>Glue g/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>296</td>
</tr>
<tr>
<td>13</td>
<td>475</td>
</tr>
<tr>
<td>22</td>
<td>1100</td>
</tr>
<tr>
<td>4</td>
<td>380</td>
</tr>
<tr>
<td>16</td>
<td>580</td>
</tr>
<tr>
<td>25</td>
<td>1340</td>
</tr>
<tr>
<td>10</td>
<td>380</td>
</tr>
<tr>
<td>19</td>
<td>858</td>
</tr>
</tbody>
</table>

Note: * - binder quantity refers to the sample surface for the given parameters

Source: Author

Testing the samples for the effect of tensile forces, the following results are shown in Figure 4.
For the obtained results a linear regression model was constructed and analysis required to understand the behaviour of the material under the conditions of given loads has been done. The SPSS software package was used to process the results.

Model. Accordingly, the normality of the distribution was tested on the prepared model. The Kolmogorov-Smirnov test was used for this purpose and the results are shown in Table 3.

Table 3
Kolmogorov-Smirnov Test

<table>
<thead>
<tr>
<th>One-Sample Kolmogorov-Smirnov Tests</th>
<th>Deformation</th>
<th>Strain</th>
<th>SPECIFIC MASS (t/m3)</th>
<th>'PU glue gr/m2 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>87</td>
<td>87</td>
<td>87</td>
<td>87</td>
</tr>
<tr>
<td>Normal Parameter sa,b</td>
<td>Mean</td>
<td>22,46</td>
<td>.55670</td>
<td>.822080</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td>13,746</td>
<td>.294599</td>
<td>.1505928</td>
</tr>
<tr>
<td>Most Extreme Differences</td>
<td>Absolute</td>
<td>.087</td>
<td>.087</td>
<td>.215</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>.087</td>
<td>.087</td>
<td>.167</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>-.068</td>
<td>-.058</td>
<td>-.215</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov Z</td>
<td>.811</td>
<td>.812</td>
<td>2.004</td>
<td>2.343</td>
</tr>
</tbody>
</table>
Asymp. Sig. (2-tailed), 526, 525, 001 <,001

a. Test distribution is Normal.

b. Calculated from data.

Source: Author

The empirical K-S value was also tested, and the test results are in Table 4.

Table 4
Model characteristics according to p K-S

<table>
<thead>
<tr>
<th>Empirical p K</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical p K</td>
<td>0.882a</td>
<td>0.778</td>
<td>0.770</td>
<td>6.593</td>
</tr>
</tbody>
</table>

Source: Author

The empirical p K-S value of 0.526 indicates that the dependent variable in the selected sample is usually distributed, the strain variable is also usually distributed, while the values of other independent variables are usually not distributed (p p values less than 5%).

The value of the determination coefficient of 0.778 suggests that the influence of deformation, material density and thickness on the deformation is interpreted as 77.8% of the change in the size of the deformation.

Multicollinearity is a potential problem in the model and has been tested.

Table 5
Determination of multicollinearity

<table>
<thead>
<tr>
<th>Model (Constant)</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>19,592</td>
<td>4,204</td>
<td></td>
</tr>
</tbody>
</table>
VIF values do not exceed limit value 5, so it has been determined that a potential multicollinear problem has been resolved.

The problem of heteroskedasticity did not exist since there was no correlation between lagged deviations and independent variables.

**Figure 5**
Deformation-strain relationship in a linear model

*Source: Author’s illustration*

Based on the obtained formed model:

\[
\delta = 19,592 + 44,401 \times n - 21,420 \times \rho - 6,155 \times Pu
\]

where:
σ - expected deformation, mm
n - strain, N / mm²
ρ - specific gravity, kg / m³
Pu - amount of polyurethane glue, kg / m²

**Model management implementation and statistical value of the model.** The test was performed with the Spearman correlation, and was conducted because of the possible relationship between the unstandardized residual values and the independent variables.

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Model testing with Spearman correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Correlations</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Unstandardized Residual</strong></td>
</tr>
<tr>
<td>Strain</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Correlation Coefficient</strong></td>
</tr>
<tr>
<td></td>
<td>,032</td>
</tr>
<tr>
<td></td>
<td><strong>Sig. (2-tailed)</strong></td>
</tr>
<tr>
<td></td>
<td>,767</td>
</tr>
<tr>
<td></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td></td>
<td>87</td>
</tr>
<tr>
<td>SPECIFIC MASS (t/m³)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Correlation Coefficient</strong></td>
</tr>
<tr>
<td></td>
<td>,012</td>
</tr>
<tr>
<td></td>
<td><strong>Sig. (2-tailed)</strong></td>
</tr>
<tr>
<td></td>
<td>,910</td>
</tr>
<tr>
<td></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td></td>
<td>87</td>
</tr>
<tr>
<td>SPECIFIC MASS (t/m³)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Correlation Coefficient</strong></td>
</tr>
<tr>
<td></td>
<td>,045</td>
</tr>
<tr>
<td></td>
<td><strong>Sig. (2-tailed)</strong></td>
</tr>
<tr>
<td></td>
<td>,678</td>
</tr>
<tr>
<td></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td></td>
<td>87</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

*Source: Author*
When checking the relationship between non-standard residual values and independent variables, no correlation was found (p values are greater than 0.05), which indicates that there are no inaccuracies in the model. Observing the trend curve, you can see that the results are located in a very close area and that there is not much scattering.

The statistical significance of the model as a whole was verified using an ANOVA test.

### Table 7

<table>
<thead>
<tr>
<th>ANOVAa</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regression</td>
<td>12641,489</td>
<td>3</td>
<td>4213,830</td>
<td>96,934</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>3608,120</td>
<td>83</td>
<td>43,471</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>16249,609</td>
<td>86</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Author

a. Dependent Variable: deformation

b. Predictors: (Constant), 'PU glue gr/m^2 (kg), SPECIFIC MASS (t/m^3), STRAIN
Based on the empirical value $F = 96.93$, it is concluded that the estimated model as a whole is statistically significant. The conclusion was drawn at the empirical level of significance $<0.001$.

**Results**

When examining the results, using statistical tools, it was concluded that the set of models is reliable with an accuracy of 78% in the estimation of deformation depending on their stress, which is visible in Table 4. The model also assumes certain spatial effects between the proposed parameters and is visible in Table no. 8:

*Table 8*

Results of the relationship of certain factors material

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformation</td>
<td>22.46</td>
<td>13.74</td>
<td>87</td>
</tr>
<tr>
<td>Strain</td>
<td>0.5670</td>
<td>0.295</td>
<td>87</td>
</tr>
<tr>
<td>SPECIFIC MASS (t/m3)</td>
<td>0.822</td>
<td>0.150</td>
<td>87</td>
</tr>
<tr>
<td>'PU glue gr/m2 (kg)</td>
<td>0.689</td>
<td>0.360</td>
<td>87</td>
</tr>
</tbody>
</table>

*Note: basic model parameters*

*Source: Author*

The table shows the following:
- The average deformation is 22.46 mm with an arithmetic mean deviation of 13.74 mm.
- Force applied resulted in deformation at which the average stress level was 0.5567 and the average arithmetic deviation was 0.295.
- Average specific gravity was 0.822 t / m3 with an arithmetic mean deviation of 0.151 t / m3.
- The amount of glue in samples averaged 0.822 kg / m2 with an arithmetic deviation of 0.36 kg / m2.

Based on the newly formed model, the following were obtained:
- With a one-time increase in stress, the voltage rises on average 44.40 mm.
- As the specific mass per unit increases, the deformation drops on average 21.42 mm.
- By increasing the amount of PU glue by 1 g / m2, the deformations are reduced by 6,155 mm.
Figure 4 shows, according to the position of the deformation curves, the relations between the samples and that the elastic properties associated with the deformation are greater for samples with a higher specific mass. It is also seen that a significant increase in the force is required for permanent deformation and breakage, which is directly related to the increase of the binder within the material structure.

Figure 5 shows that the results at lower values of the applied force and the resulting deformation are very close to the tendency curve, while with the increase of the force and the deformation there is a "dissipation" and distance from the tendency curve. This results in a decrease in the percentage of model estimation accuracy.

The biggest relative influence on the deformation is the stress where any change of stress for one standard deviation can be expected to increase the deformation by an average of 0.952 standard deviations.

Discussion

The model turned out to be good in terms of approach to solving problems. However, its accuracy is 78%, and 80% is not required to be considered acceptable. Given a slight lag to the required limit, it was found that the results can be processed statistically, but with a change in the model, until the accuracy is within acceptable limits. Since it was shown that there is increased “scattering” around the trend curve, this is considered the reason why the model did not give satisfactory results.

Conclusion

When applying statistical models, it is important to emphasize that the accuracy of the estimation refers to deviations from the average value or from the arithmetic mean of the presented results. This study is an indication that on this number of samples with the default parameters are not capable of being applied linear model. The accuracy obtained is 78% and the required minimum accuracy is 80%. It is necessary to increase the number of samples tested or continue processing with another more complex model.

The results of the study form a model for estimating certain deformations with respect to given parameters. This directly indicates that the recipe of the material may be affected by deformation. If the required recipe is known, there is also an impact on the economic aspect of the material.

In order to continue processing the results by statistical methods, exponential or logarithmic functions will be used in the continuation of the study, which can give better and more accurate processing of the results and thus a more accurate model for estimating the deformation values for given parameters. Ultimately, with this approach, the composition of the material can be modelled and the parameters required for the purposeful use of the finished product can be affected.
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About the author

Andjelko Crnoja, Ph. Student of Odessa State Academy of Civil Engineering and Architecture in Odessa, Ukraine. Designer in the field of structural physics, narrow field noise protection. Research into the application of new recycled rubber-based materials in the field of structural structures. Research and application of recycled car tire panels to improve the sound insulation and other properties of lightweight metal structures. Development and application of new construction products based on recycled rubber for the protection of noisy noise sources in residential and industrial buildings. The author can be contacted at acrnoja@hotmail.com.
Investigation of Residual Bearing Capacity of Inclined Sections of Damaged Reinforced Concrete Beams

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Abstract

The article reports on the results of the numerical and the laboratory tests to determine the effect of concrete damages near support areas in compressed zone of the reinforced concrete beams on their residual bearing capacity of inclined sections. According to the experimental plan, 15 single-span freely supported experimental samples with dimensions of 100×200×1200 mm made with different artificial damages within the shear span $a_v$ (1d, 2d, and 3d) were tested. The numerical test of prototypes was performed in software complex LIRA-SAPR 2017. The results of laboratory and numerical experiments showed good convergence regarding the bearing capacity, however, the nature of the fracture in samples B11-B14 did not match. Empirical - conducting laboratory experiments on samples using modern methods of measurement; numerical modelling – using software complex LIRA-SAPR 2017; analysis and statistical processing of the obtained research results; comparison of the obtained results; abstraction; generalization; deduction; formulation of the main conclusions and recommendations. The analysis found that the bearing capacity decreases with increased area of damage and shear span. Conducting the calculations in software complex LIRA-SAPR allows to predict the work elements and determine the bearing capacity with good accuracy, but in comparison with the real data there still are some differences in the character of destruction.

Keywords: experimental, beams, damage, residual capacity
Introduction

During the analysis of literature, it was established that the research strength of the inclined sections was shown in the works of famous local and foreign scientists. However, the study of the strength of the inclined sections in the damaged beams has not been conducted and is currently relevant. In particular, in the future it will be very interesting to study the impact of damages in the compressed zone of concrete in the form of chips with different values of the shear span.

Today, there are a number of methods for calculating reinforced concrete elements under the action of transverse forces. Calculation methods began to develop during the first studies of the operation of reinforced concrete elements, it turned out that the destruction of the samples under study occurs not only along normal cracks, but also along the inclined ones. During experiments with a series of Talbot A.N. (Talbot, 1909) beams, the idea of the operation of a reinforced concrete element after the formation of cracks as a spacer system was proposed.

Reinforced concrete is a relatively durable material and may serve for a long time, the vast amount of concrete structures operated with considerable exploitation terms (Klymenko, 2010). Unfortunately, during its operation, concrete structures definitely undergo deterioration and/or damages, cracking, corrosion of reinforcement, concrete corrosion, mechanical damages (such as chipped concrete), damages from construction errors, damages from exposure to elevated temperatures, damages from accidental effects of freeze-thaw cycles, etc. (Zoran et al., 2015; Lu et al., 2015; Ou and Sun, 2107; Blikharskyi, 2011). Subsequently, the first reasonably appropriate method was proposed, which was based on the so-called "truss" analogy - an analogy between a reinforced concrete element that perceives lateral forces and a diagonal truss (Johnson et al.,1981; Klymenko et al., 2019; Pavlikov et al., 2011; Dorofeev et al., 2010; Zalesov et al., 2002; Voskobiynyk et al., (2011,2016), Garkava et al., 2018; Karpyuk et al., 2016; Vegera, 2016; Bondarenko et al., 2003). According to this method, in a reinforced concrete element, the upper zone is the concrete of the compressed zone, the squeezed brackets are the concrete of the wall, the lower zone is the stretched reinforcement, the truss struts are vertical transverse reinforcement, the extended braces are transverse inclined reinforcement (bends). In the existing national building codes (BS EN 1992-1-1:2004) there are no instructions or guidance on determining residual bearing capacity of damaged concrete structures. That is why theoretical and experimental research and development of methods for its determination were done.

At the Odessa State Academy of Civil Engineering and Architecture a lot of studies of the residual bearing capacity of concrete elements were conducted by Klymenko, Ye.
V. (from 2006 till present) and his PhD students. According to the results of these studies a number of methods to determine residual bearing capacity of damaged concrete columns, beams for normal sections, etc. were suggested (Klymenko and Arez, 2011; Orešković et al., 2018; Klymenko et al., 2013). But studies of residual bearing capacity of damaged beams inclined sections in the compressed area are not carried out and there is no available scientific information in sources.

Nowadays, reinforced concrete has become one of the main materials for the construction of objects of any complexity for a number of its positive features, such as: high strength, fire resistance, density, ability to resist both static and dynamic loads, earthquake resistance, durability. The durability of reinforced concrete structures can reach, under certain favorable conditions, more than 100 years, thereby exceeding even the designated service life during design. But under unfavorable conditions (improper operation, design errors, exposure to an aggressive environment, increased loads on the structure after reconstruction or modernization of equipment, mechanical and various types of damage), on the contrary, lead building structures into emergency conditions and force repairs to be carried out even earlier than this provided by the Ukraine and Croatian building norms. In the conditions of the difficult economic situation of the country in our time, it is very important to extend the life of buildings and structures, since it is much cheaper in comparison with new construction. The topic of the article is directly related to and corresponds to the topic financed by the Ukrainian state for the development of the entire Ukrainian region "Restoration of the performance of reinforced concrete building structures damaged during operation and military activity."

**Methodology**

The method of evaluation of residual bearing capacity in the software complex LIRA-SAPR 2017, non-destructive method is proposed in this article. At the first stage, the points on coordinates are created, which are later connected and the boundary conditions to nodes in five degrees of freedom are set. At the second stage, the stiffness of the elements is set. Using the "Hardness → Hardness Elements" menu, the "Elemental Hardness" dialog is called. In this window, click on the "Add" button to display the list. Choose the third dialog "Plastic, Volume, Numerical", the type of section - "Volume Limit Elements", and then put a tick on the account of nonlinearity and press "parameters of the material", choose the "law of nonlinear deformation", in our case, it is 14 (piecewise -linear law of deformation), and then data on the characteristics of the material from the received graph of the dependence of "stress-deformation" are introduced. The beams were divided into finite elements in the form of rectangular parallelepipeds with a face dimension of 1 to 2 cm, as well as octal and six-node endpoints in the form of triangular and quadrangular prisms in places where this required the geometry of the sample for modeling the slope of the shelves and the front of the damage.
The laying was given by physically nonlinear spatial eight-node and six-node isoparametric FEs of type 236 - "physically nonlinear universal spatial 8-node isoperimetric Limit Elements" and a metal plate for the transfer of load FEs of type 234, taking into account geometric and physical nonlinearity.

According to the plan of the experiment, 15 one-span reinforced concrete beams of the size 100×200×1200 mm and working span 1000 mm were made and tested. For control samples concrete cubes and prisms were identified, concrete grade used for samples - C25/30; for control samples for reinforcing bars longitudinal working rebars were determined - Ø18 mm of grade A500C, mounting longitudinal and transverse reinforcement in the form of vertical links - Ø6 mm of grade A240C. At the ends of longitudinal working bars reinforcing short-bars are welded to ensure reliable anchoring.

The influence of three factors on the bearing capacity is studied – the shear span \(a\) (1d, 2d, and 3d), the depth of damage \(h\) (0, 50 and 100 mm) and the angle of inclination of the damage \(\beta\) (0°, 30°, 60°). For measuring the strain of bars within the shear span, on the surface of transverse reinforcing bars strain gauges with a base of 10 mm were glued. To measure the deformation of concrete beams on the surface of concrete strain gauges with a base of 50 mm were glued. Sectional beams with dimensions of damages and values of shear span on codes samples are shown in Figures 1, 2 and Table 1.

The laboratory tests of beams were conducted on the universal power plant using hydraulic jacks, which produced the loading. The samples were loaded stepwise in the form of a concentrated force \(F_u\) within the relative shear range \(a_v\) with uniformly increasing steps.
**Figure 1**

Samples characteristics

![Diagram](image)

*Source: Author’s illustration*

**Table 1**

Samples characteristics

<table>
<thead>
<tr>
<th>Call number</th>
<th>Depths of damage $h_1$, mm</th>
<th>Angle of damage $\beta_1$, °</th>
<th>Shear span $\alpha_y$, °</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>0</td>
<td>0</td>
<td>3d</td>
</tr>
<tr>
<td>B2</td>
<td>50</td>
<td>30</td>
<td>3d</td>
</tr>
<tr>
<td>B3</td>
<td>50</td>
<td>60</td>
<td>3d</td>
</tr>
<tr>
<td>B4</td>
<td>100</td>
<td>30</td>
<td>3d</td>
</tr>
<tr>
<td>B5</td>
<td>100</td>
<td>60</td>
<td>3d</td>
</tr>
<tr>
<td>B6</td>
<td>0</td>
<td>0</td>
<td>2d</td>
</tr>
<tr>
<td>B7</td>
<td>50</td>
<td>30</td>
<td>2d</td>
</tr>
<tr>
<td>B8</td>
<td>50</td>
<td>60</td>
<td>2d</td>
</tr>
<tr>
<td>B9</td>
<td>100</td>
<td>30</td>
<td>2d</td>
</tr>
<tr>
<td>B10</td>
<td>100</td>
<td>60</td>
<td>2d</td>
</tr>
<tr>
<td>B11</td>
<td>0</td>
<td>0</td>
<td>1d</td>
</tr>
<tr>
<td>B12</td>
<td>50</td>
<td>30</td>
<td>1d</td>
</tr>
<tr>
<td>B13</td>
<td>50</td>
<td>60</td>
<td>1d</td>
</tr>
<tr>
<td>B14</td>
<td>100</td>
<td>30</td>
<td>1d</td>
</tr>
<tr>
<td>B15</td>
<td>100</td>
<td>60</td>
<td>1d</td>
</tr>
</tbody>
</table>

*Source: Author’s calculation*
Figure 2

Samples reinforcement characteristics

Source: Author's illustration
Results

Results of laboratory tests

For the destruction criterion of beams one of the criteria was accepted: the excessive values of deformation of concrete or reinforcement rebar, the excessive values width of opening cracks, the excessive values beam deflections. The results of the test showed that all prototypes were destroyed on the inclined sections – prevailing action of the transverse force leads to significantly revealed inclined cracks in the samples and concrete was destroyed above the crack top. The bars of the transverse reinforcement began to yield in samples B1...B4, B6...B8, B11. Typical destruction nature of experimental samples is shown in Figure 3.

Figures should be submitted as separate documents in jpg, jpeg or tiff format. Figures should have minimum resolution of 300 dpi. Every figure should have an individual title. Use italic font and capitalize each word (except and, in, of, with, etc.). For example: Macroeconomic indicators.

Breaking load and transverse forces in the experimental samples are shown in Table 2.

Table 2

Samples characteristics

<table>
<thead>
<tr>
<th>Call number</th>
<th>Ultimate force $F_{u}$, kN</th>
<th>Ultimate transverse force $V_{u}$, kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>121,62</td>
<td>59,59</td>
</tr>
<tr>
<td>B2</td>
<td>116,62</td>
<td>57,14</td>
</tr>
<tr>
<td>B3</td>
<td>98,29</td>
<td>48,16</td>
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<tr>
<td>B4</td>
<td>96,63</td>
<td>47,35</td>
</tr>
<tr>
<td>B5</td>
<td>49,98</td>
<td>24,49</td>
</tr>
<tr>
<td>B6</td>
<td>133,28</td>
<td>87,96</td>
</tr>
<tr>
<td>B7</td>
<td>99,96</td>
<td>65,97</td>
</tr>
<tr>
<td>B8</td>
<td>93,296</td>
<td>61,58</td>
</tr>
<tr>
<td>B9</td>
<td>73,304</td>
<td>48,38</td>
</tr>
<tr>
<td>B10</td>
<td>56,644</td>
<td>37,39</td>
</tr>
<tr>
<td>B11</td>
<td>158,27</td>
<td>131,36</td>
</tr>
<tr>
<td>B12</td>
<td>149,94</td>
<td>124,45</td>
</tr>
<tr>
<td>B13</td>
<td>139,944</td>
<td>116,15</td>
</tr>
<tr>
<td>B14</td>
<td>124,95</td>
<td>103,71</td>
</tr>
<tr>
<td>B15</td>
<td>106,624</td>
<td>88,5</td>
</tr>
</tbody>
</table>

Source: Author’s calculation
Figure 3
Experimental samples destruction nature B1, B4, B11…B14 (laboratory tests)

Results of numerical tests

Numerical tests of the samples were performed on the software complex LIRA-SAPR. This software complex makes calculations based on the finite element method. Its advantage is the ability to perform non-linear steps iterative calculation using the actual stress-strain diagrams "σ-ε" for materials. Criterion of the destruction of experimental samples was taken to achieve one of the conditions: stresses in the compressed concrete reached ultimate values, stresses in the reinforcement reached
ultimate values, significant fast-growing movements of the elements of the design scheme.

*Figure 4*

Experimental samples destruction nature B1, B4, B11...B14 (numerical tests)

*Source: Author's figure*
Comparative breaking loads and transverse forces in the experimental samples are shown in Table 3.

<table>
<thead>
<tr>
<th>Call number</th>
<th>Ultimate force (numerical test) $F_{u}^{ira}$, kN</th>
<th>Ultimate force (laboratory test) $F_{u}^{exp}$, kN</th>
<th>Ultimate transverse force (numerical test) $V_{u}^{ira}$, kN</th>
<th>Ultimate transverse force (laboratory test) $V_{u}^{exp}$, kN</th>
<th>Difference $\left(\frac{V_{u}^{exp} - V_{u}^{calc}}{V_{u}^{exp}}\right) \times 100%$, %</th>
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</thead>
<tbody>
<tr>
<td>B1</td>
<td>111,24</td>
<td>121,618</td>
<td>54.51</td>
<td>59.54</td>
<td>8.45</td>
</tr>
<tr>
<td>B2</td>
<td>105.6</td>
<td>116,62</td>
<td>51.74</td>
<td>57.14</td>
<td>9.46</td>
</tr>
<tr>
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<td>90.828</td>
<td>98,294</td>
<td>44.51</td>
<td>48.16</td>
<td>7.59</td>
</tr>
<tr>
<td>B4</td>
<td>88.56</td>
<td>96,628</td>
<td>43.39</td>
<td>47.35</td>
<td>8.36</td>
</tr>
<tr>
<td>B5</td>
<td>46.2</td>
<td>49,98</td>
<td>22.64</td>
<td>24.49</td>
<td>7.55</td>
</tr>
<tr>
<td>B6</td>
<td>124,2</td>
<td>133,28</td>
<td>81.97</td>
<td>87.98</td>
<td>6.83</td>
</tr>
<tr>
<td>B7</td>
<td>121.41</td>
<td>99,96</td>
<td>80.13</td>
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</tr>
<tr>
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<td>79.8</td>
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<td>61.58</td>
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</tr>
<tr>
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<td>78</td>
<td>73,304</td>
<td>51.48</td>
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<tr>
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<td>56,644</td>
<td>32.71</td>
<td>37.39</td>
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<tr>
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<td>136.5</td>
<td>158,27</td>
<td>113.3</td>
<td>131.36</td>
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</tr>
<tr>
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<td>149,94</td>
<td>110.06</td>
<td>124.45</td>
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<tr>
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<td>103.58</td>
<td>116.15</td>
<td>10.83</td>
</tr>
<tr>
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<td>100.35</td>
<td>103.7</td>
<td>3.23</td>
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<tr>
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<td>86.85</td>
<td>106,624</td>
<td>72.09</td>
<td>88.5</td>
<td>18.54</td>
</tr>
<tr>
<td>Z</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65.68</td>
</tr>
<tr>
<td>$\sigma$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.02</td>
</tr>
<tr>
<td>$\nu$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14.81</td>
</tr>
</tbody>
</table>

**Discussion**

The results of experimental and theoretical studies have made it possible to create a model for the calculation of inclined sections of damaged reinforced concrete beams of rectangular cross section, which can be applied in the practice of construction, reconstruction of buildings and structures, which will allow a rational approach to the issue of reinforcing and repairing damaged flexing elements, knowing their residual bearing capacity. The database of laboratory and theoretical data was supplemented on bearing capacity, deformation, cracks and deflections of reinforced concrete beams. According to the experimental data it can be seen that increasing the shear span $\nu$ (from $1d$ to $3d$) leads to reducing the bearing capacity in the samples. Obtained data also show that bearing capacity decreases with an increase in the area.
of damage. Analysis of the obtained data showed that the character of destruction nature is the same as character of destruction for laboratory tests – prevailing action of the transverse force leads to significantly revealed inclined cracks in the samples and concrete was destroyed above the crack top, the exception is character of destruction for samples B11..B14. In these samples, destruction was due to the destruction of concrete on a support. Also, there is a difference in the yielding of the transverse reinforcement bars – they did not begin to yield in any sample.

According to the obtained experimental data it can be seen that results of residual bearing capacity conducted in the software complex LIRA-SAPR are very close to the results of the laboratory tests. It is evidenced by the coefficient of variation \( \nu = 14,81\% \).

**Conclusion**

Conclusion should be based on answering the research questions and/or should include the results of hypothesis investigation. Limitations of the study should be noted and further research directions should be proposed.

The experimental research of determining the residual bearing capacity of inclined sections for damaged reinforced concrete beams of rectangular section was conducted. The results of laboratory and numerical studies showed that with an increase in the depth or volume of damage and an increase in the relative shear span \( a_\nu \), the value of the bearing capacity in the samples decreased. Conducting the calculations in software complex LIRA-SAPR allows the prediction of the work elements and determination of the bearing capacity with good accuracy, but in comparison with the real data there are still some differences in character of destruction. Operating with the received data we are planning to submit proposals regarding the calculation of residual bearing capacity of damaged reinforced concrete beams inclined sections of rectangular section. In further research, it is planned to develop proposals for calculating the residual bearing capacity of inclined sections of damaged reinforced concrete elements to select a reinforcement method.

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From a policy bank to a crowding-in bank: The development of the European Investment Bank in the last ten years, as seen through its business model

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University of Luxembourg

Abstract

The European Investment Bank (EIB), the primary financial arm of the European Union (EU) has become of central interest in the last ten years. The EIB has been increasingly solicited by the EU to bolster the European economy during the global crisis and support its recovery thereafter. Calls have recently been voiced for the EIB to contribute to the European Green Deal and the post-pandemic economic stimulus. This paper studies the EIB’s role in the European economy through its business model in the period from 2009–2019. The paper’s prime objective is to investigate what enabled the EIB to act in a countercyclical mode and how the EIB met the new economy needs in this turbulent environment.

Keywords: Business Model, European Investment Bank (EIB), Institutional Governance

Paper type: Research article

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Introduction

The European Investment Bank (EIB), the primary financial arm of the European Union (EU) took centre stage following the economic crisis in 2008. In the ten-year period of 2009–2019, the EIB has been called upon to act in a countercyclical mode by increasing its lending amid the economic crisis and subsequently promote the EU’s smart, sustainable and inclusive growth. More recently, the EIB has been solicited to bolster the EU’s Green Deal announced in late 2019 and redress the consequences of the pandemic in 2020.

In this context, academic interest in the EIB has recently increased, although it does not match the bank’s economic and political clout. Academic literature focuses mainly
on the EIB's financing activity (Liebe & Howarth 2019; Clifton et al., 2018; Anghel et al. 2016; Clifton et al. 2014; Pistoia 2014; Marzinotto 2011; Fedele et al. 2010). This paper aims to complement existing scholarly work by examining the EIB as an organisation in the last ten years. It will address the following questions: What enabled the EIB to act in a countercyclical mode? What enabled the EIB to meet the new needs in this turbulent environment?

Following a Popperian approach, this paper studies the EIB as an organisation for a period in which its policies and practices constitute trial solutions to prevailing economic and social problems. To answer the research questions, the paper examines the EIB's business model. An organisation's business model describes how it creates and delivers value, providing a unique vantage point from which to observe the organisation (Calvante et al. 2011; Johnson et al. 2008; Osterwalder 2004; Zott et al. 2011). A business model contains strategy and activity parameters, and it unveils a business's structure and processes, so it can be used to plan an organisation's future but also to study its past and present. Although the EIB's officials have made frequent reference to its business model, these have been short verbal descriptions connected with the bank's triple-A credit rating (EIB 2010; Szymczak 2010; EIB 2011; Camdessus, M. 2010, p. 19). Given the implicit link with EIB's rating, the bank's recent references have been diversified, coining the name “EIB's financial model” (EIB 2019b, p. 18). The EIB's business model has never been available in the public domain. Nevertheless, this paper presents the EIB's business model, crafted based on a hybrid archetype devised by the author to match the bank's dual nature as an EU body and a bank. Based on an existing archetypal model (Johnson et al. 2008) and reflecting the affinity diagram of business models' components (Schafer et al. 2005), this hybrid model consists of four primary interlocking elements that reflect the institutional side and the banking side of the EIB: a) strategic choices, which describe the core logic; b) value capture, which refers to the capabilities and competencies that secure the resources needed for the organisation's viability; c) value creation, which concerns how the organisation delivers its value proposition to the client; and d) value network, which pertains to the internal and external support web of staff, stakeholders, peers, and suppliers. The EIB's institutional side consists primarily of its strategic choices and, to a lesser extent, its value network, whereas the value creation and value capture elements reflect the EIB's banking side. This generic hybrid model has been tailored to the EIB by filling in its elements with the EIB's business fundamentals. As an EU body, the EIB's fundamentals are contained in the bank's statute (EIB 1999; OJEU 2016) and are in the public domain, as they form an integral part of the EU's treaties (Edward & Lane 2013).

The review of the EIB's statutes overtime reveals that only two of them resulted in business model revisions (Kavvadia 2018). These revisions, which took place in 1999 and 2010, were driven to a great extent by a mixture of European policy and market developments, reflecting the introduction of the Euro and the difficult economic environment in the EU before and during the global economic crisis. The November 2019 announcement of the EIB's pivot to become the first international climate bank and its statutory modification following the United Kingdom's departure from the EU
in March 2020 are beyond the scope of the present analysis. This paper focuses on the EIB’s 2010 model, which was applied until the end of the ten-year period under review. Benchmarking the model by the EIB's annual performance, the analysis shows that the model is well conceived and has proven robust and flexible, allowing for the bank's inorganic and organic growth. Inorganic growth means growth originating from external political calls for activity, which the EIB has fulfilled, acting as a policy-taker. Organic growth refers to the EIB's augmented activity resulting from the extension of its normal business and to cases when the EIB acts as a policy-maker (Mertens & Thiemann 2019) or policy entrepreneur (Liebe & Howarth 2019), promoting policies and products that suit its operational plans. The bank was consequently able not only to fulfil its remit in support of European policies but also to boost its own organisational objectives.

This paper adds to existing work and contributes to scientific research by studying the EIB to improve understanding of its function as an organisation.

The paper is organised as follows: the next section presents the EIB's business model for the ten-year period of concern, analyses the model and attempts to explain how it bolstered the bank’s activity over this turbulent period. The conclusion briefly summarises the paper’s major findings.

Mastering the turbulent crisis environment: An “all-weather” business model?

The business model under study has been in force since 2010, coinciding with the spread of the economic crisis in the EU. It was crafted, however, based on previous deliberations at the EU’s and EIB's top levels. This model is a consolidation and extension of the EIB's 1999 model—the model's first revision since the bank's establishment in 1957—which is presented in Figure 1, with the relevant changes to the 2010 model underlined in the diagram in Figure 2. These changes were introduced gradually, reflecting Lindblom's incrementalism (Lindblom 1959). Characterised by a remarkable flexibility in interpreting European policy-makers' objectives, the EIB's 1999 business model enabled the bank to develop from mono-focus activity, such as regional development and, later, market-making or investment promotion (Clifton et al. 2014, 2018), to multi-foci activity for smart, sustainable and inclusive growth. The 1999 revision of the business model was deemed necessary because of the cataclysmic changes leading up to the Euro's introduction concerning both investment supply and demand under the prevailing financial conditions. The enlarged, liquid single-Euro capital markets bred fierce competition among issuers in terms of interest rates. On the demand side, the Maastricht criteria restricted public financing of investments and curtailed lending demand. Against this backdrop and amid a reshaping of economic governance, the EIB had to remain useful to the EU, which was seeking growth against all odds. The EIB faced some challenges: i) high lending volumes to publicly financed infrastructure projects could no longer be expected, and ii) a turn to increased private lending was challenging, as EIB's fine interest rates were no longer attractive to private borrowers, who could tap the vast,
liquid Euro capital markets, while the single currency dissipated the EIB’s ability to lower rates through arbitrage.

The global economic crisis created a different situation. On the supply side, existing liquidity sought good investment prospects in capital markets, and EIB’s triple-A was exceptionally attractive amid several sovereign downgrades. On the demand side, however, investment plans were arrested, as public finance was devastated by the sovereign debt crisis and private finance was put on hold due to prevailing uncertainties and consumption collapse. The EIB’s 2010 business model revision therefore aimed predominantly to redress demand difficulties. EU policy decisions, partly stemming also from the EIB’s activism (Liebe & Howarth 2019), resulted in change to the EIB’s strategic choices, which triggered concomitant modifications in all four elements of its business model. However, this study’s analysis shows that these changes were carried out primarily in the value capture and the value network elements of the bank’s business model.

To address private sector needs, the EIB’s offering remained focused on lending but pivoted to increased leverage, achieving higher investments with the same amount of funding through so-called special activities. These special activities included risk capital and equity participation and structured finance. To increase its leverage—in other words, to obtain a higher multiplier for its lending and hence a greater impact on new investment creation through these special activities—the EIB focused on: i) blending its own funds with EU Commission resources; ii) upgrading the role of the European Investment Fund (EIF), the EIB’s subsidiary, by distinguishing more clearly between venture-capital funding and lending, respectively, aiming to increase intra-group coherence, complementarity and efficiency; iii) developing new financial roles, such as bond purchaser and underwriter; and iv) institutionalising its long-claimed catalyst role, by monetizing its human resources by providing advisory services.

Paired mainly with the European Commission, the EIB’s advisory services were offered through the Joint Initiatives and, later, the European Fund for Strategic Investments (EFSI) as part of the “Juncker Plan.” These advisory services also extended its public–private partnerships (PPPs) expertise into a further consulting area (Liebe & Howarth 2019). The EIB’s activism in this area had already begun under its 1999 business model, resulting in the creation of the European PPP Expertise Centre (EPEC) in 2008. EPEC was further developed under the bank’s 2010 model as a way to continue the EIB’s funding of infrastructure projects despite the public sector retreat. Building on its value network and its strength as a catalyst for large infrastructure financing, the EIB recently described itself as a “crowding-in bank” (EIB 2019b, p. 12). This term implies that the EIB’s due-diligence process provides a quality shield to projects, paving the way for commercial banks and other investors to crowd-in. Unlike commercial banks, the EIB’s project appraisals go beyond financial risk to include market, economic, environmental and technological risks.

In its catalyst role, the EIB also cultivates synergies with other financiers. Since 1999, the EIB has sought to cooperate with other Multilateral Development Banks (MDBs), as shown by the increasing number of agreements in the form of Memoranda of
Understanding. These memoranda have resulted in mutual benefits including i) enrichment of their client base and project pipelines by cross-sharing projects; ii) denting operating costs by sharing project appraisal tasks; iii) paring down project and borrower/guarantor risks through risk-sharing, resulting in improved asset quality; and iv) affirmation of their relevance by demonstrating an efficient use of public funding through cooperation.

The EIB also scaled up its partnership with commercial banks and national promotional agencies (NPAs). The EIB has striven to cooperate with national banking systems since its establishment. Even if it filled market failures, supra-national public funding could not be easily justified if it competed with commercial banks, which are valuable national interests. This is especially the case because organisations seek parallel market opportunities when filling market failures.

As the Bank pointed out in its first Annual Report in 1958, by creating not another fund, but a bank, the six member states: set aside more direct financial intervention methods which no doubt would not in the long run have enabled adequate resources to be raised. They particularly wished the promotion of investments . . . to be carried out by existing banking houses . . . That is, they wished to utilise the commercial world banking system, with the EIB providing ‘an additional source of financing which might prove decisive’ in creating or furthering projects they wanted realised. (Lewenhak 1982, p. 23)

Since its conception, the EIB has been a complementary source of finance with its funding limited to a maximum of 50%, or in exceptional cases 75%, of the total project cost, allowing other financiers to take part in its deals. Cooperation with the banking network has always been a project purveying channel for the EIB, especially for reaching small- and medium-sized enterprises (SMEs), which historically represent about 30% of EIB annual lending, and other direct or indirect loans, mainly with a commercial bank as the intermediary borrower. The EIB’s cooperation with the banking system not only increases the lending activity of all actors but also mitigates their risks through aggregation and sharing. The EIB also cooperates with commercial banks in guarantee operations, guaranteeing their loans or vice versa, which historically represents about 30% of all EIB guarantees. The banking sector, an important partner of the EIB on its borrowing side, has benefited from commissions and fees on the EIB’s vast emission programmes while often using the EIB’s SMEs financing lines—known as global loans—as treasury funding. The EIB’s partnership with commercial banks has enabled it to function for about 40 years with no active client solicitation in its business model until 1999. Customer and investor relations were further strengthened in the 2010 model through an increased number of direct contacts in the form of road shows, fora, national and regional conferences, global relations management (GRM) and a new worldwide office network, which includes about 50 regional offices from all continents in the last 10 years.

The objectives added to the EIB’s 1999 model, such as human capital and innovation, allowed the bank to refocus from a limited number of specific policy foci, notably regional development and market-making activities (Clifton et al. 2014), to multiple
foci, covering “smart, sustainable and inclusive growth”. These objectives were applied flexibly to match the ever-evolving European requirements, in support of the Lisbon Agenda in 2000, the European Action for Growth in 2003 and the Europe 2020 Initiative in 2009, which led to the EIB's consequent endorsement by successive EU Councils. Despite its success, the EIB's 1999 business model had to be revised within ten years to adapt to the pre-crisis and global crisis context characterised by sluggish investment despite abundant liquidity. The EIB's 2010 model aimed to channel inactive liquidity into investments by enabling the EIB to carry higher risks, thereby further increasing the bank's competitiveness and relevance. The 2010 model went well beyond a quantitative increase of EIB lending volumes, which would have had unspectacular results, considering the EIB's lending from 2010–2017 represented only 2.5% of the EU's GDP and 10% of the EU's gross fixed capital formation (GFCF). The model's revisions therefore targeted the qualitative turn of EIB lending, prioritising new areas for promoting smart and inclusive growth, such as human capital and innovation. By their nature, however, investments in these areas bear greater risks and require adapted finance products. The increased risk-taking and risk-sharing products the EIB had started to test and implement under its 1999 business model came to the fore to be further developed, strengthened and complemented with new ones to achieve increased leverage. Unlike several of its peer MDBs, the EIB's resultant scaled-up risk appetite and leverage carried low intrinsic risk, allowing the bank to maintain its top-notch triple-A rating. The EIB's low intrinsic risk is due to the value capture element of its business model, which has demonstrated several key strengths that characterise the EIB and differentiate it from its peers: a) strong shareholders' support, as evidenced by successive capital increases and the resulting metrics (EIB 2017; EIB 2016); b) strained yet satisfactory capital adequacy, thanks to its strong asset quality; c) low-risk operating environment, as the EIB has provided about 90% of the lending in the EU's highly developed shareholder countries; d) diversified loan portfolio in terms of geographical, sectoral and counterparty-type; e) adequate liquidity with a twelve-month buffer, strengthened further by the bank's access to the European Central Bank (ECB)'s liquidity facilities, which is almost unique among peer MDBs; f) prudent risk management enhanced by the EIB's preferred creditor status (PCS) (EIB, 2016), which is also rare among peer MDBs; g) high asset quality, due to the high-quality borrowers who approach the EIB and the bank's due-diligence and guarantee requirements; h) externalisation of operations bearing the highest risk to the EU or member states—a unique feature among its peers, giving the EIB an advantage over other MDBs (Kavvadia, 2020)—which means it enjoys guarantees for its portfolio outside the EU and within the EU for high-risk projects.

The EIB's qualitative turn to new areas of priority was supplemented by a further improvement to its business model in 2010. This model institutionalised the blending of EU grants with EIB loans for better, more efficient and effective coordination of European funding for investment projects. The EIB has always cooperated and coordinated with the Commission, its sister institution, in terms of policy, financial support of European priority areas and EU funding channelled through the EIB under the mandate of prime policy areas. Examples within the EU include the New
Community Instrument (NIC), topical natural catastrophe interventions and, more recently, the EFSI and most EIB operations outside the EU. This EIB feature of cooperating with the Commission is unique among MDBs and has been further extended in the bank's 2010 model to blend EIB resources at market rates with the Commission's grants under the Structural Funds, resulting in reduced aggregate funding costs. Cost reductions being paid upfront, the cost reductions that are achieved through injecting grants into projects' finance plans have better effects on investments than interest-rate subsidies; these cost reductions provide front-loaded relief during the initial phases of a project's realisation, when start-up costs are high and cash flow rarely reaches target levels, while their present net value is higher. With such cost reductions, EIB's lending terms became even more competitive. These cost reductions were attractive to project promoters, allowing the EIB to maintain its market share amid the fierce competition of the Euro euphoria period, and they enabled the EIB's countercyclical intervention during the crisis years.

Beyond the funding blend, the closer cooperation between the EIB and the Commission was also institutionalised through a number of Joint Initiatives concerning SMEs, urban renewal and technical assistance to infrastructure projects. These initiatives benefited the EIB by enlarging its customer base, reaching 530 new advisory assignments in 2018 (EIB, 2019c:3), while increasing its income from advisory services fees. The Joint Initiatives also enriched the Commission's technical skills. Additionally, the qualitative improvements foreseen in the 2010 model triggered concrete benefits for the European investment scene by i) buffeting the EIB's multiplier effect for more impactful lending; ii) scaling up investment through cross-sharing projects among MDBs; and iii) developing new investment proposals through advisory services, which assisted in the design and setup of bankable projects. Furthermore, these three qualitative improvements constituted the springboard for EIB's increased activity in support of the EU's counter-crisis efforts for recovery and growth. The EIB's contribution to these EU efforts has not been limited to its normal activity. It has received an additional and considerable thrust through the EFSI, which was created in the framework of the Juncker Investment Plan in 2015. Beyond higher lending volumes, the EFSI focused on changing the qualitative profile of projects to be financed through increased risk-taking, "eyeing" in particular projects in "strategic infrastructure, education, RDI, renewable energy and resource efficiency, as well as support for SMEs and Midcaps" (EIB 2016, p. 1). Carrying a higher-than-average credit risk embedded in the EIB's portfolio, loans under the EFSI benefit from the EU guarantee representing 25% of the total (for bolstering the EIB's value creation element) while EFSI equity and mezzanine instruments were also guaranteed by the EU.

This type of EIB activity, with part of the risk exported to the EU, will continue because the bank is also expected to play an important role in InvestEU (EIB, 2019a), the Juncker Plan's successor. InvestEU will be based on a 38 billion EUR guarantee from the EU budget, with the aim of mobilising 650 billion EUR of investment to allow the EU to remain “social, green and competitive” (EIB, 2019a). Entrusting the implementation of the Juncker Plan and its forthcoming successor InvestEU to the EIB
confirmed anew the bank’s European mandate, which constitutes an integral part of the bank’s future development, as mentioned by its president: “InvestEU, from our perspective—from the perspective of investment and growth—is about transforming EFSI into a long-term, robust and financially sustainable tool to support EU policy delivery, notably in those key areas of innovation, climate and cohesion that I mentioned a minute ago” (EIB 2019b, p. 11). Nevertheless, InvestEU dethrones the EIB from its privileged and long-held position as the sole counterparty of the EU’s major financing initiatives, which places the bank at par with other financial organisations, such as the National Promotional Banks (NPBs). Still, by guaranteeing project risks, InvestEU will allow the bank to continue playing an important role—albeit smaller, entrusting the EIB with only 75% of the funds—in economic sectors of prime European importance, such as innovation and climate enhancement. However, InvestEU is intended to demonstrate higher efficiency and effectiveness than the Juncker Plan by introducing competition among the financial actors, including the EIB and NPBs, while spreading risk more widely among EIB and NPBs. InvestEU has therefore been conceived with a higher multiplier of 17 than that of the original EFSI at 15. Through higher leveraging, EU funding is expected to have an increased impact and outturn investment amounts. While it is required to move into riskier projects, the EIB continues to be soothed by EU guarantees for prudently implementing such requested activities. As riskier loans consume larger parts of capitalisation, the 2012 capital increase and the 2020 capital replenishment have bolstered the effectiveness and resilience of the EIB’s value capture element. Conversely, if these riskier loans are provided to successful investment schemes, they offer high returns; the EIB has therefore turned from a “non-profit-making” (EIB, 1988:1) to a “non-profit-maximising” (EIB, 2011:41) organisation.

To improve the leverage of the combined EU budget and EIB resources, the bank’s 2010 business model institutionalised a three-pillar activity in its strategic choices element, namely lending, blending and advising. This three-pillar structure has allowed the EIB not only to develop multi-foci activity but also to devise and test, in parallel and under one roof, five different types of business and banking: a) wholesale banking for SME financing via partner banks; b) development banking for financing outside the Union; c) for-profit banking for risk-taking and -sharing operations; d) policy banking for EU priority projects’ financing; and e) banking for advisory services. With these five different banking lines under one roof, the EIB enjoys full flexibility for its resource and cost allocation, able to pursue the most promising activity at any given time against the backdrop of ever-changing political, economic and market conditions. In the turbulent economic environment characterised by challenges, such as the globalization of the supply and demand sides of the real and the financial economies, climate change, and the economic crisis, the EIB’s 2010 business model has proved itself robust, well crafted, pertinent and sufficient for the bank to not only survive but thrive in the pre-crisis, crisis and post-crisis periods, as shown in this analysis and as demonstrated in EIB’s results. The EIB has consequently maintained its relevance by unceasingly supporting the ever-changing EU policies when it is called to succour, while being supported in this by the same political masters who demand
its contribution. While upholding its support for regional development as well as economic and social cohesion in the EU, the EIB’s activity has been shifting to a new priority of anti-crisis boosting economic activity, including human capital development, innovation, competitiveness and SMEs, as well as climate change mitigation. At the end of 2019, climate change mitigation was touted as the EIB’s prime future priority when it pivoted to become the first international climate bank in support of the European Green Deal. In 2020, its new tasks will include supporting post-pandemic economic recovery and InvestEU, which constitute a challenge for EIB’s activity consistency in its endeavours to fulfil different mandates, of which some have contradictory objectives. Further research on EIB’s 2020 business model could shed light on how the EIB will align with these activities.

Conclusion

Since its establishment, the EIB has grown into a prominent EU institution with global clout. Its development and importance in European policy implementation, as well as its formation (Liebe & Howarth, 2019; Mertens & Thiemann, 2019) have accelerated in the last ten years. During this period, the EIB has been called to bolster the European economy during the global crisis by acting in a countercyclical mode and to support its recovery thereafter. To gain increased leverage, its activity has soared in volume, enlarging its sector reach, expanding into advisory services and diversifying qualitatively to cater to higher-risk projects. The EIB’s business model has proven itself flexible, allowing inorganic and organic growth, while remaining solid in a turbulent economic environment. This is mainly due to the EIB’s institutional nature and, in particular, to its strong shareholder support, its affinity with the Commission and the ECB and its pairing with peers and the banking sector. The EIB’s institutional nature allows the bank to adapt its activity to EU calls, while its bank side is retrofitted by the EU to alleviate possible risks. Although there are changes in EIB’s post-Brexit statute in 2020, foreseeing, “along with the financial measures, a number of governance changes are planned” (EIB 2019b, p. 4), the above schema is expected to extend into the future. InvestEU, the Green Deal and the EU’s response to the pandemic aim to deepen the blending of resources and the ties between the EIB and its sister institution, the Commission, in a “concept of an integrated partnership,” as stated by the EIB’s president (EIB 2019b, p. 12).
Figure 1 The European Investment Bank 1999 business model

Source: Author's Illustration
Figure 2 The European Investment Bank 2010 business model

Source: Author's illustration
References


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