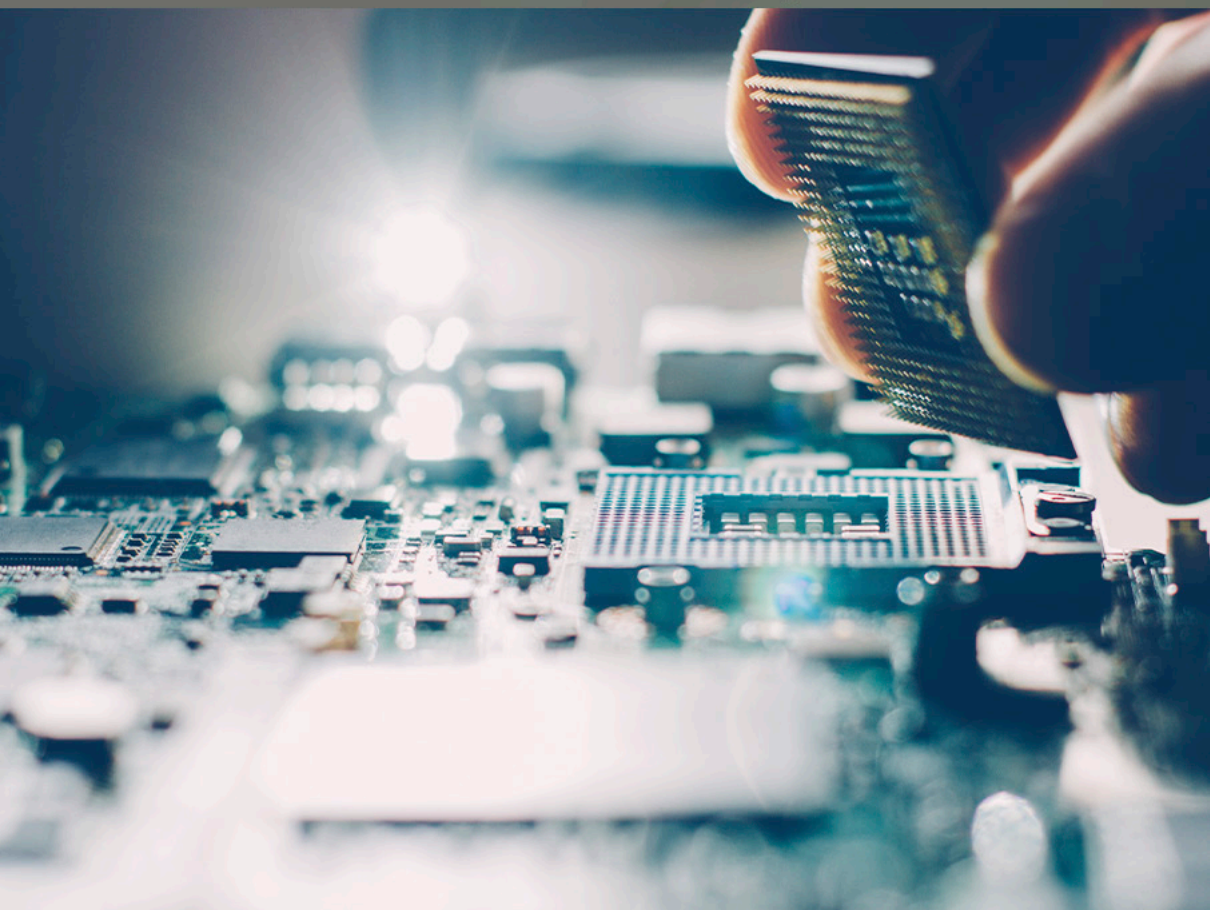


COLEÇÃO

DESAFIOS DAS ENGENHARIAS:

ENGENHARIA DE COMPUTAÇÃO 3

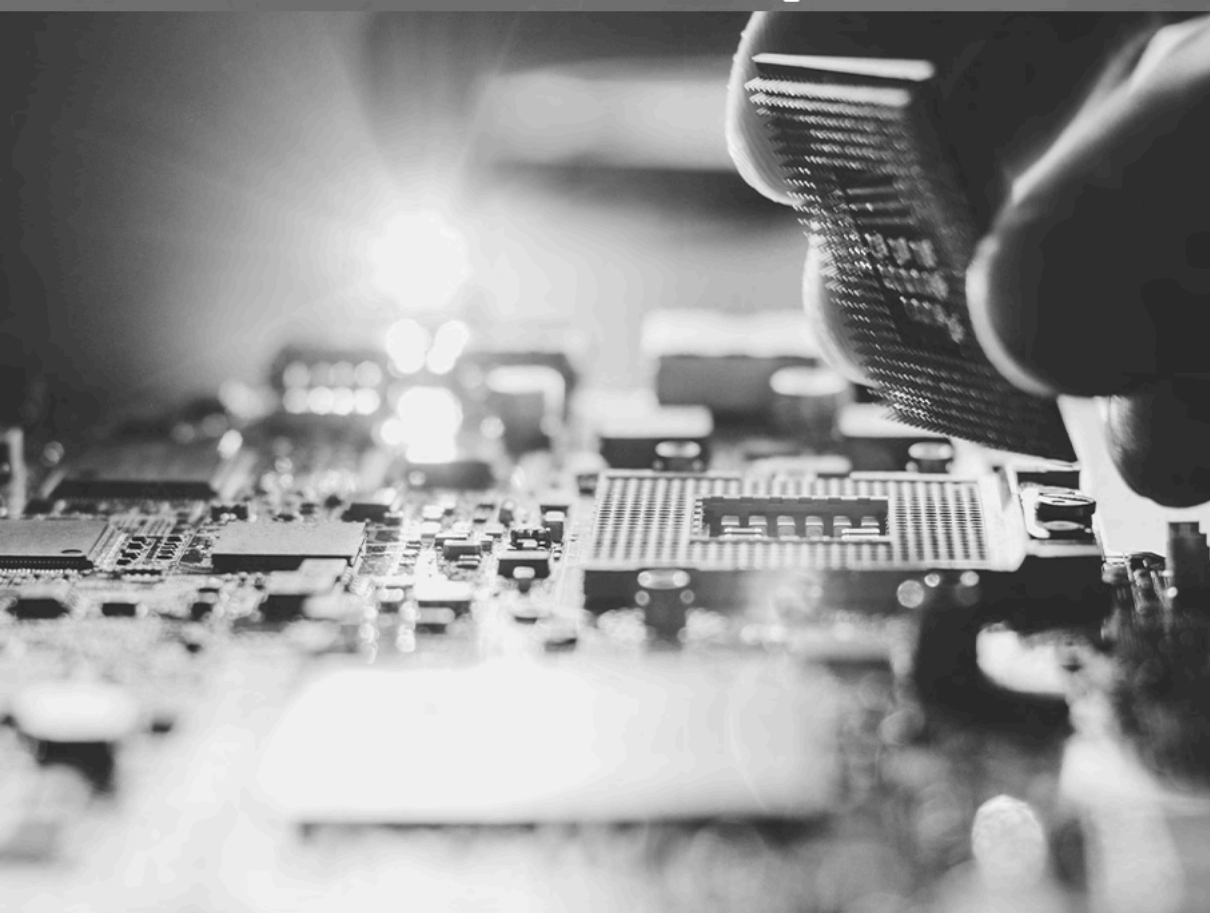


LILIAN COELHO DE FREITAS
(ORGANIZADORA)

Atena
Editora
Ano 2021

COLEÇÃO
DESAFIOS
DAS
ENGENHARIAS:

ENGENHARIA DE COMPUTAÇÃO 3



LILIAN COELHO DE FREITAS
(ORGANIZADORA)

Atena
Editora
Ano 2021

Editora chefe

Profª Drª Antonella Carvalho de Oliveira

Editora executiva

Natalia Oliveira

Assistente editorial

Flávia Roberta Barão

Bibliotecária

Janaina Ramos

Projeto gráfico

Camila Alves de Cremo

Daphynny Pamplona

Gabriel Motomu Teshima

Luiza Alves Batista

Natália Sandrini de Azevedo

Imagens da capa

iStock

Edição de arte

Luiza Alves Batista

2021 by Atena Editora

Copyright © Atena Editora

Copyright do texto © 2021 Os autores

Copyright da edição © 2021 Atena Editora

Direitos para esta edição cedidos à Atena Editora pelos autores.

Open access publication by Atena Editora



Todo o conteúdo deste livro está licenciado sob uma Licença de Atribuição *Creative Commons*. Atribuição-Não-Comercial-NãoDerivativos 4.0 Internacional (CC BY-NC-ND 4.0).

O conteúdo dos artigos e seus dados em sua forma, correção e confiabilidade são de responsabilidade exclusiva dos autores, inclusive não representam necessariamente a posição oficial da Atena Editora. Permitido o *download* da obra e o compartilhamento desde que sejam atribuídos créditos aos autores, mas sem a possibilidade de alterá-la de nenhuma forma ou utilizá-la para fins comerciais.

Todos os manuscritos foram previamente submetidos à avaliação cega pelos pares, membros do Conselho Editorial desta Editora, tendo sido aprovados para a publicação com base em critérios de neutralidade e imparcialidade acadêmica.

A Atena Editora é comprometida em garantir a integridade editorial em todas as etapas do processo de publicação, evitando plágio, dados ou resultados fraudulentos e impedindo que interesses financeiros comprometam os padrões éticos da publicação. Situações suspeitas de má conduta científica serão investigadas sob o mais alto padrão de rigor acadêmico e ético.

Conselho Editorial

Ciências Exatas e da Terra e Engenharias

Prof. Dr. Adélio Alcino Sampaio Castro Machado – Universidade do Porto

Profª Drª Ana Grasielle Dionísio Corrêa – Universidade Presbiteriana Mackenzie

Prof. Dr. Carlos Eduardo Sanches de Andrade – Universidade Federal de Goiás

Profª Drª Carmen Lúcia Voigt – Universidade Norte do Paraná

Prof. Dr. Cleiseano Emanuel da Silva Paniagua – Instituto Federal de Educação, Ciência e Tecnologia de Goiás

Prof. Dr. Douglas Gonçalves da Silva – Universidade Estadual do Sudoeste da Bahia
Prof. Dr. Eloi Rufato Junior – Universidade Tecnológica Federal do Paraná
Profª Drª Érica de Melo Azevedo – Instituto Federal do Rio de Janeiro
Prof. Dr. Fabrício Menezes Ramos – Instituto Federal do Pará
Profª Dra. Jéssica Verger Nardeli – Universidade Estadual Paulista Júlio de Mesquita Filho
Prof. Dr. Juliano Carlo Rufino de Freitas – Universidade Federal de Campina Grande
Profª Drª Luciana do Nascimento Mendes – Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Norte
Prof. Dr. Marcelo Marques – Universidade Estadual de Maringá
Prof. Dr. Marco Aurélio Kistemann Junior – Universidade Federal de Juiz de Fora
Profª Drª Neiva Maria de Almeida – Universidade Federal da Paraíba
Profª Drª Natiéli Piovesan – Instituto Federal do Rio Grande do Norte
Profª Drª Priscila Tessmer Scaglioni – Universidade Federal de Pelotas
Prof. Dr. Sidney Gonçalo de Lima – Universidade Federal do Piauí
Prof. Dr. Takeshy Tachizawa – Faculdade de Campo Limpo Paulista

Diagramação: Daphynny Pamplona
Correção: Gabriel Motomu Teshima
Indexação: Amanda Kelly da Costa Veiga
Revisão: Os autores
Organizadora: Lilian Coelho de Freitas

Dados Internacionais de Catalogação na Publicação (CIP)

C691 Coleção desafios das engenharias: engenharia de computação 3 / Organizadora Lilian Coelho de Freitas. – Ponta Grossa - PR: Atena, 2021.

Formato: PDF

Requisitos de sistema: Adobe Acrobat Reader

Modo de acesso: World Wide Web

Inclui bibliografia

ISBN 978-65-5983-619-2

DOI: <https://doi.org/10.22533/at.ed.192212911>

1. Engenharia de computação. I. Freitas, Lilian Coelho de (Organizadora). II. Título.

CDD 621.39

Elaborado por Bibliotecária Janaina Ramos – CRB-8/9166

Atena Editora

Ponta Grossa – Paraná – Brasil

Telefone: +55 (42) 3323-5493

www.atenaeditora.com.br

contato@atenaeditora.com.br

DECLARAÇÃO DOS AUTORES

Os autores desta obra: 1. Atestam não possuir qualquer interesse comercial que constitua um conflito de interesses em relação ao artigo científico publicado; 2. Declaram que participaram ativamente da construção dos respectivos manuscritos, preferencialmente na: a) Concepção do estudo, e/ou aquisição de dados, e/ou análise e interpretação de dados; b) Elaboração do artigo ou revisão com vistas a tornar o material intelectualmente relevante; c) Aprovação final do manuscrito para submissão.; 3. Certificam que os artigos científicos publicados estão completamente isentos de dados e/ou resultados fraudulentos; 4. Confirmam a citação e a referência correta de todos os dados e de interpretações de dados de outras pesquisas; 5. Reconhecem terem informado todas as fontes de financiamento recebidas para a consecução da pesquisa; 6. Autorizam a edição da obra, que incluem os registros de ficha catalográfica, ISBN, DOI e demais indexadores, projeto visual e criação de capa, diagramação de miolo, assim como lançamento e divulgação da mesma conforme critérios da Atena Editora.

DECLARAÇÃO DA EDITORA

A Atena Editora declara, para os devidos fins de direito, que: 1. A presente publicação constitui apenas transferência temporária dos direitos autorais, direito sobre a publicação, inclusive não constitui responsabilidade solidária na criação dos manuscritos publicados, nos termos previstos na Lei sobre direitos autorais (Lei 9610/98), no art. 184 do Código Penal e no art. 927 do Código Civil; 2. Autoriza e incentiva os autores a assinarem contratos com repositórios institucionais, com fins exclusivos de divulgação da obra, desde que com o devido reconhecimento de autoria e edição e sem qualquer finalidade comercial; 3. Todos os e-book são *open access, desta forma* não os comercializa em seu site, sites parceiros, plataformas de *e-commerce*, ou qualquer outro meio virtual ou físico, portanto, está isenta de repasses de direitos autorais aos autores; 4. Todos os membros do conselho editorial são doutores e vinculados a instituições de ensino superior públicas, conforme recomendação da CAPES para obtenção do Qualis livro; 5. Não cede, comercializa ou autoriza a utilização dos nomes e e-mails dos autores, bem como nenhum outro dado dos mesmos, para qualquer finalidade que não o escopo da divulgação desta obra.

APRESENTAÇÃO

A Atena Editora tem a honra de presentear o público em geral com a série de *e-books* intitulada “*Coleção desafios das engenharias: Engenharia de computação*”. Em seu terceiro volume, esta obra tem o objetivo de divulgar aplicações tecnológicas da Engenharia de Computação na resolução de problemas atuais, com o intuito de facilitar a difusão do conhecimento científico produzido em várias instituições de ensino e pesquisa do país.

Organizado em 20 capítulos, este volume apresenta temas como utilização de aprendizagem de máquina na avaliação de riscos de infecção por COVID-19; dispositivos automatizados para administração de remédios; comunicação científica apoiada por realidade aumentada; métodos de elementos finitos aplicados na análise de materiais para indústria aeronáutica; aplicações de processamento digital de imagens e de algoritmos genéticos; entre diversas outras aplicações da automação e do desenvolvimento de *software*, combinados para melhorar as atividades do nosso dia-a-dia.

Dessa forma, esta obra contribuirá para aprimoramento do conhecimento de seus leitores e servirá de base referencial para futuras investigações.

Os organizadores da Atena Editora, agradecem especialmente os autores dos diversos capítulos apresentados, parabenizam a dedicação e esforço de cada um, os quais viabilizaram a construção deste trabalho.

Boa leitura.


Lilian Coelho de Freitas

SUMÁRIO

CAPÍTULO 1..... 1

EVALUATING THE RISK OF COVID-19 INFECTION BASED ON MACHINE LEARNING OF SYMPTOMS AND CONDITIONS VERSUS LABORATORY METHODS


Daniel Mário de Lima
João Henrique Gonçalves de Sá
Ramon Alfredo Moreno
Marina de Fátima de Sá Rebelo
José Eduardo Krieger
Marco Antonio Gutierrez

 <https://doi.org/10.22533/at.ed.1922129111>

CAPÍTULO 2..... 16

DISPOSITIVO AUTOMATIZADO PARA ADMINISTRAÇÃO DE REMÉDIOS


João Roberto Silva Teixeira
Alessandro Mainardi de Oliveira
Ricardo Neves de Carvalho

 <https://doi.org/10.22533/at.ed.1922129112>

CAPÍTULO 3..... 22

INTEGRAÇÃO ENTRE DADOS TEXTUAIS DE PRONTUÁRIOS ELETRÔNICOS DO PACIENTE (PEPS) E TERMINOLOGIAS CLÍNICAS


Amanda Damasceno de Souza
Eduardo Ribeiro Felipe
Fernanda Farinelli
Jeanne Louize Emygdio
Livia Marangon Duffles Teixeira
Maurício Barcellos Almeida

 <https://doi.org/10.22533/at.ed.1922129113>

CAPÍTULO 4..... 35

COMPARATIVE ANALYSIS OF THE PERFORMANCE OF A ENRICHED MIXED FINITE ELEMENT METHOD WITH STATIC CONDENSATION FOR POISSON PROBLEMS

Ricardo Javier Hanco Ancori
Jose Diego Ayñayanque Pastor
Rómulo Walter Condori Bustincio
Eliseo Daniel Velasquez Condori
Roger Edwar Mestas Chávez
Fermín Flavio Mamani Condori
Jorge Lizardo Díaz Calle


 <https://doi.org/10.22533/at.ed.1922129114>

CAPÍTULO 5..... 45

COMPORTAMENTO DE PAREDE DE ALVENARIA ESTRUTURAL EM SITUAÇÃO DE INCÊNDIO: ANÁLISE NUMÉRICA

Jean Marie Désir


Luana Zanin

 <https://doi.org/10.22533/at.ed.1922129115>

CAPÍTULO 6..... 58

COMUNICAÇÃO CIENTÍFICA APOIADA POR REALIDADE AUMENTADA: O CASO DO APLICATIVO AUMENTANDO KIRIMURÊ


Vinícius Pires de Oliveira
Fernanda Vitória Nascimento Lisboa
Jéssica Duarte Souza
Brisa Santana Brasileiro
Hilma Maria Passos de Oliveira
Ingrid Winkler
Andrea de Matos Machado
Karla Schuch Brunet

 <https://doi.org/10.22533/at.ed.1922129116>

CAPÍTULO 7..... 64

CONTEXTUALIZAÇÃO DO CPS DE UMA CÉLULA ROBÓTICA, ATRAVÉS DO GÊMEO DIGITAL UTILIZANDO PROTOCOLO DE COMUNICAÇÃO OPC UA


Rogério Adas Pereira Vitalli

 <https://doi.org/10.22533/at.ed.1922129117>

CAPÍTULO 8..... 75

DESENVOLVIMENTO DE UMA ARQUITETURA DE SOFTWARE BASEADA EM CENÁRIOS ARQUITETURAIS, MEMORANDOS TÉCNICOS E VISÕES DO MODELO 4+1


Everson Willian Pereira Bacelli
Bruno Ferreira Cardoso
Wilson Vendramel

 <https://doi.org/10.22533/at.ed.1922129118>

CAPÍTULO 9..... 90

DEVELOPMENT OF AN AIDING TOOL FOR THE OPTIMAL DETAIL OF ACTIVE REINFORCEMENT USING GENETIC ALGORITHM

Victória Carino Neves
Guilherme Coelho Gomes Barros







 <https://doi.org/10.22533/at.ed.1922129119>





CAPÍTULO 10..... 106

ANÁLISE DOS EFEITOS DA MÉTRICA DE DISTÂNCIA NA EXTRAÇÃO DE CONJUNTOS DE SIMILARIDADE

André Eduardo Alessi
Bruno Duarte
Ives Renê Venturini Pola
Dalcimar Casanova
Marco Antonio de Castro Barbosa

 <https://doi.org/10.22533/at.ed.19221291110>

CAPÍTULO 11	119
ESTUDO SOBRE AUTOMATIZAÇÃO DE EQUIVALÊNCIA DE FUNÇÕES	
Lucas Fernando Frighetto Fábio Hernandez	
 https://doi.org/10.22533/at.ed.19221291111	
CAPÍTULO 12	142
ESTUDO SOBRE O CONTROLE REMOTO DE DISPOSITIVOS MICROCONTROLADOS UTILIZANDO DISPOSITIVOS MÓVEIS	
João Vítor Fernandes Dias Fermín Alfredo Tang Montané	
 https://doi.org/10.22533/at.ed.19221291112	
CAPÍTULO 13	163
HERRAMIENTAS TECNOLÓGICAS APLICADAS EN EL DIBUJO ASISTIDO POR COMPUTADORA EN LA MODALIDAD A DISTANCIA	
Liliana Eneida Sánchez Platas Celia Bertha Reyes Espinoza Olivia Allende Hernández	
 https://doi.org/10.22533/at.ed.19221291113	
CAPÍTULO 14	174
HISTÓRICO DAS MULHERES NA TECNOLOGIA DA INFORMAÇÃO E ANÁLISE DA PARTICIPAÇÃO FEMININA NOS CURSOS SUPERIORES DO BRASIL	
Vívian Ludimila Aguiar Santos Thales Francisco Mota Carvalho Maria do Socorro Vieira Barreto	
 https://doi.org/10.22533/at.ed.19221291114	
CAPÍTULO 15	186
IDENTIFICAÇÃO DO MODELO DINÂMICO DE UMA TURBINA EÓLICA: ESTUDO DE CASO DA NORDTANK NTK 330F	
Gustavo Almeida Silveira de Souza Edgar Campus Furtado Leandro José Evilásio Campos Cristiane Medina Finzi Quintão	
 https://doi.org/10.22533/at.ed.19221291115	
CAPÍTULO 16	199
COMFORT IN VIBRATIONS FOR THE STEEL-CONCRETE COMPOSITE FLOORS: AN APPRAISAL FOR REVIEW OF ABNT NBR 8800:2008	
João Vitor V. Freire André V. Soares Gomes Adenílcia Fernanda G. Calenzani Johann A. Ferrareto	
 https://doi.org/10.22533/at.ed.19221291116	

CAPÍTULO 17	224
FINITE ELEMENT METHOD APPLIED TO MECHANICAL ANALYSIS OF AERONAUTICAL RIBS IN CARBON FIBER AND 7075 ALUMINUM ALLOY	
Alex Fernandes de Souza	
 https://doi.org/10.22533/at.ed.19221291117	
CAPÍTULO 18	236
MÉTODO PARA CALCULAR A ÁREA DE SUPERFICIAL DE RAÍZES POR PROCESSAMENTO DIGITAL DE IMAGENS	
Marcio Hosoya Name	
 https://doi.org/10.22533/at.ed.19221291118	
CAPÍTULO 19	244
LOCAL MESHFREE METHOD OPTIMIZATION WITH GENETICALGORITHMS	
Wilber Vélez	
Flávio Mendonça	
Artur Portela	
 https://doi.org/10.22533/at.ed.19221291119	
CAPÍTULO 20	258
NAVEGACIÓN VIRTUAL 2D Y 3D EN UN ENTORNO WEB	
Víctor Tomás Tomás Mariano	
Felipe de Jesús Núñez Cárdenas	
Jorge Hernández Camacho	
Isaura Argüelles Azuara	
Guillermo Canales Bautista	
 https://doi.org/10.22533/at.ed.19221291120	
SOBRE A ORGANIZADORA	268
ÍNDICE REMISSIVO	269

COMFORT IN VIBRATIONS FOR THE STEEL- CONCRETE COMPOSITE FLOORS: AN APPRAISAL FOR REVIEW OF ABNT NBR 8800:2008

Data de aceite: 01/11/2021

João Vitor V. Freire

André V. Soares Gomes

Adenílcia Fernanda G. Calenzani

Federal University of Espírito Santo
ES/Vitória, Brazil

Johann A. Ferrareto

ArcelorMittal Global R&D South America Center
of Tubarão, Brazil
ES/Serra, Brazil

ABSTRACT: Steel-concrete composite floors often have human comfort for excessive vibrations as the most critical Service Limit State, in which vibration-sensitive floor systems must be designed so as to avoid the unacceptable transient oscillations due to the walking of people or due to other sources. According to ABNT NBR 8800:2008 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008), this limit state is designed by controlling the natural frequency of the floor under service loads, keeping it above a certain threshold, generally from 3.0Hz to 4.0Hz for the most common cases according to its Annex “L”. The main objective of this article is to propose a bibliographic review on the evaluation of comfort for floors, based on their dynamic characteristics, such as natural frequency (f_n), modal mass (M_{mod}) and damping (D) to obtain speed values ($OS-RMS_{90}$) and acceleration (peak), when applying dynamic loads as predicted by Sedlacek (SEDLACEK et al., 2006) 5.25%. The object of

study is a steel-concrete composite slab of a steel construction at the Federal University of *Espírito Santo* (UFES, Brazil). After analytical calculations and numerical modeling with dynamic loads, the floor is instrumented and kinematic results (velocity and acceleration) are compared between model and experiment. By means of spectral analyzes of vibration energy, stiffness gains by concrete ageing are observed for calibration of the model, accordingly to Ji Young Kim (KIM et al., 2009) finite element (FE). Finally, the answers of a questionnaire about comfort answered by the occupants are discussed and compared with international publications to integrate new comfort thresholds and analysis methodology in the new related chapter of ABNT NBR 8800:2008, currently under review.

KEYWORDS: Vibrations; Human Comfort; Steel-concrete

1 | INTRODUCTION

According to ISO 10137 (ISO 10137, 2007), the tendency of using more resistant materials leading to lighter, slender and less stiff solutions increases the susceptibility of modern structures to vibration problems, leading to greater responsibility for such structural assessments by the design engineer. Similarly, proper functioning of laboratory and industrial processes and instruments, work efficiency and human well-being increase the demand for “vibration free” environments.

In this context, a subject that has always

been present is that of vibrations in steel-concrete composite and metallic floor structures, whose amplitudes are controlled, in accordance with NBR 8800:2008 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008), by limiting static deflections and natural frequencies. However, according to ISO 10137 (ISO 10137, 2007), unsatisfactory vibration levels have been observed in buildings, which seems to indicate that the indirect criteria, such as the adopted by Brazilian standard, for example, are no longer adequate.

Lighter compositions have emerged from the use of high strength materials such as steel, of computer aid for design and of LRFD (Load and Resistance Factor Design) for optimization of structure calculation based on force requirements. In addition, as set out in an analysis of vibrations and the design of a structure subject to the stimulation of human walking, by M. Setareh and M. Lovelace (SETAREH; LOVELACE, 2010) innovative architect designs due to the demand for column free spaces, i.e., large beam spans, are a cause for reduced natural frequency and damping, which aggravates the discomfort of vibration.

Thus, according to Sedlacek (SEDLACEK et al., 2006)5.25%, by determining the dynamic characteristics of a floor, such as natural frequency (f_n), modal mass (M_{mod}) and damping (D) it is possible to get the value OS-RMS90 (velocity value for a step comprising 90% of the steps of persons walking normally and corresponding to the harmonic vibration caused by the step on the floor) and to determine the vibration acceptance class according to **Table 1**, adapted from data presented by Sedlacek (SEDLACEK et al., 2006)5.25%, with the aid of diagrams such as in **Fig. 1**. Such diagrams demonstrate that in the same set of and , even frequencies often have an acceptance class lower than their previous odd frequency. Therefore, the relationship that the lower the frequency is, the worse the acceptance class will be is not valid, since, for certain modal mass and damping values, a 3 Hz frequency may characterize a better degree of acceptance than a 4Hz frequency, as show in **Fig. 1**. Such fact, associated with the rhythm of the human step, contrasts with the minimum limit of 4Hz imposed by the Brazilian Standard NBR 8800:2008 (item L.3.2) (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008) for floors where people walk regularly, such as homes and offices.

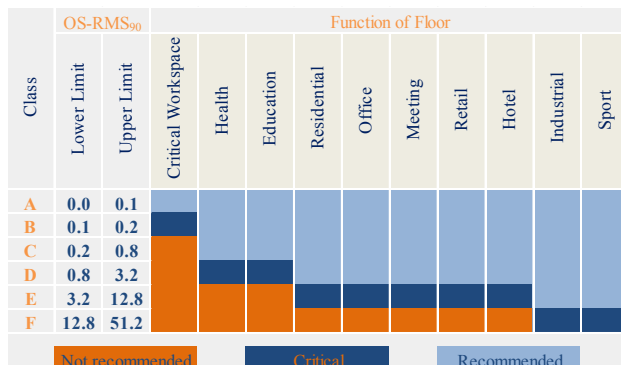


Table 1. Floor response rating and recommendation for class application (FELDMANN; HEINEMEYER; VOLLING, 2008)

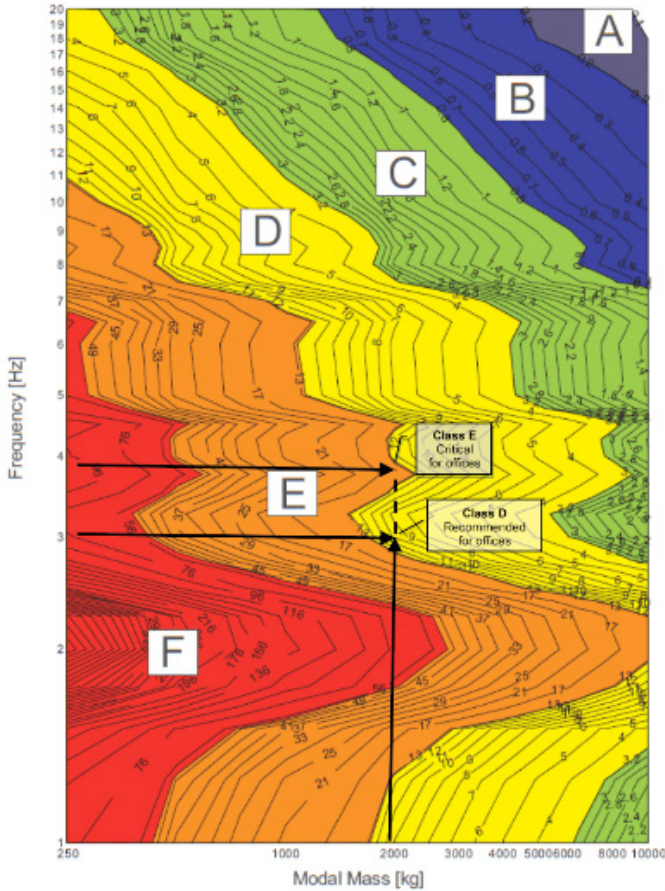


Figure 1. OS-RMS90 and floor response rating, both for damping ratio of 4% (SEDLACEK et al., 2006)5.25%.

Therefore, using as a study object a building in steel and steel-concrete composite structures, the Center of Excellence in Metallic and Steel-concrete Composite Structures (from Portuguese, NEXEM), exposed in **Fig. 2**, of Federal University of Espírito Santo (from Portuguese, UFES), it is intended to predict, by modeling and simulation in ANSYS 19.0, and to measure, by beam testing, the vibration levels from one of the building rooms. Finally, numerical results are compared and a comfort questionnaire, submitted to building users, provides a qualitative analysis of vibration levels.



Figure 2. NEXEM, UFES [personal collection].

2 | METHODOLOGY

The research methodology to achieve the objectives of this article follows the model literature review, case study and analysis of results, in accordance with the flowchart presented in Fig. 3. It starts with a brief study on floor comfort assessment based on the dynamic characteristics of a floor, as presented in item 1 of this paper.

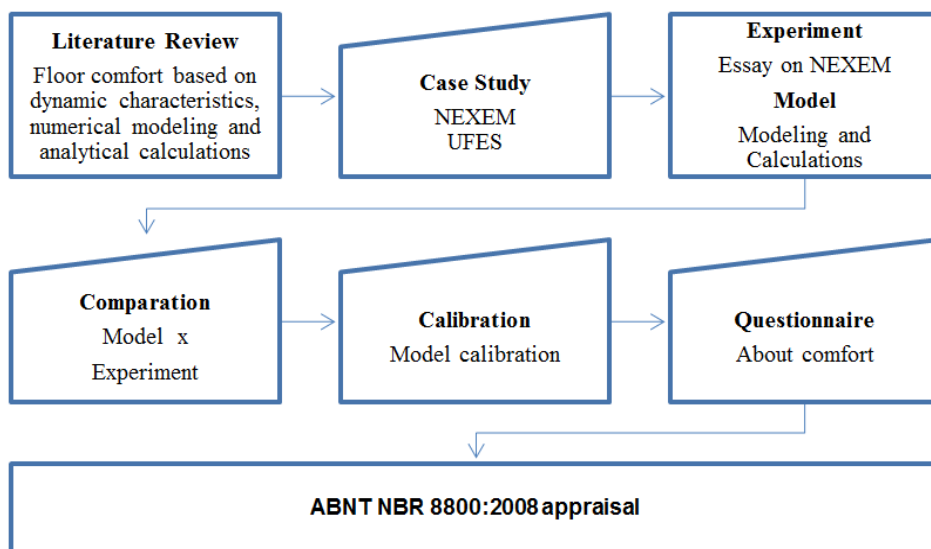


Figure 3. Methodology flowchart [personal collection]

Subsequently, taking the study object, NEXEM, the numerical modeling in ANSYS 19.0

is performed. After, one of the rooms of the building under study has its floor instrumented to obtain acceleration values as a function of time from induced stimuli at the time of the test, values which are treated in MATLAB.

Given the data obtained by the test, the vibration energy spectral analysis is performed for further comparison between the model and the experiment. Thus, it is possible to observe stiffness gains due to concrete aging for the model calibration.

Comfort questionnaires are distributed to the occupants of the unit evaluated and the answers obtained are discussed and compared to international publications. According to the results obtained, an appraisal is made to the chapter on ABNT NBR 8800:2008 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008) ongoing review, in order to integrate it new comfort limits and analysis methodologies.

2.1 ANALYTICAL CALCULATIONS AND DESIGN PROCESS

Computational spreadsheet calculations, in turn, are used to obtain the natural frequency and the modal mass of the steel-concrete composite beam analyzed, as well as the system of the beams plus slab. For this purpose, the following input data presented in the **Table 2** are requested.

Variable	Description	Dimension
F_G	Value of permanent load applied to structure	[kg/m ²]
F_Q	Variable/accidental load value applied to structure	[kg/m ²]
$\%_{FQ,RMS90}$	Variable load reduction factor applied to structure	[%]
L_V	Beam length	[m]
L_F	Beam Distance	[m]
$L_{V,P}$	Main beam length	[m]
$f_{1,V,P}$	Natural frequency of a second beam connected to the analyzed beam	[Hz]
ρ_a	Specific steel mass adopted	[kg/m ³]
ρ_c	Specific mass of concrete adopted	[kg/m ³]
f_{ck}	Characteristic compressive strength of concrete	[MPa]

f_y	Steel yield strength	[MPa]
f_u	Tensile strength of steel	[MPa]
E_a	Steel modulus of elasticity	[GPa]

Table 2. Input variables.

The natural frequency of a second beam connected to the analyzed beam, $f_{1v,p}$ [Hz], is previously calculated by the same worksheet or obtained in numerical modeling. There are still the input variables h_t , h_F , b_b , b_m and b_n , that represent the geometry of the concrete slab and are exposed in **Fig. 4** and the variables $b_{f,sup}$, $b_{f,inf}$, t_w , $t_{f,sup}$, and $t_{f,inf}$, which represent the cross-section geometry of the steel profile I beam and are exposed in **Fig. 5**.

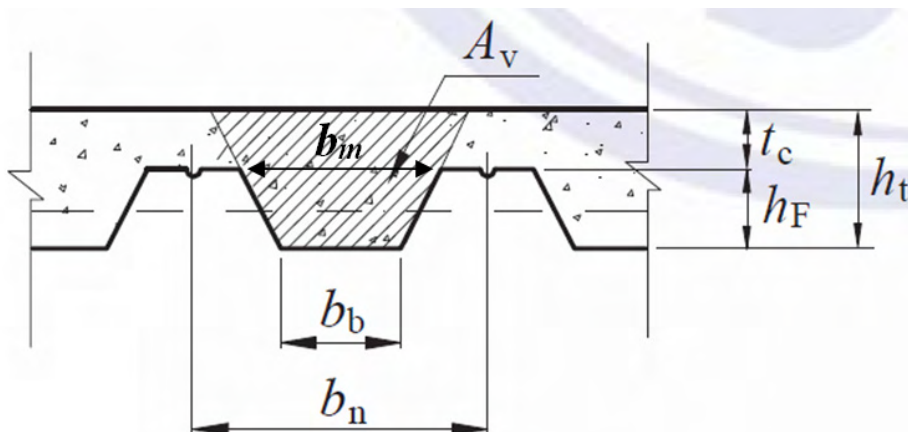


Figure 4. Concrete slab dimensions (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008).

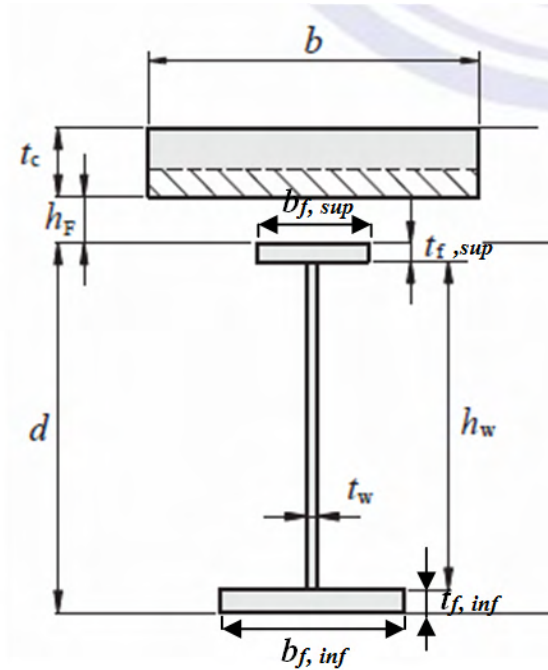


Figure 5. Steel beam dimensions (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008).

After entering those data, the following results are generated according to the formulas and considerations made to be presented in **Table 3** and in **Table 4**.

Variable	Description	Dimension
A	Steel beam cross section area	$[m^2]$
$I_{y,t}$	Moment of inertia of slab profile around y (vertical axis) per meter	$[m^4/m]$
$E_{y,C.D.}$	Y-stiffness (vertical axis) of steel-concrete composite beam section for short duration loads	$[N.m^2]$

Table 3. Calculated variables.

Variable	Description e Dimension	Equation	Subtitle
$E_{\dot{c}}$	Concrete modulus of elasticity [GPa]	$5.6\sqrt{f_k} + 0.9$	(1)
μ_a	Steel beam linear specific mass [kg/m]	$A \square r_a$	(2)
μ_g	Steel-concrete composite beam linear specific mass [kg/m]	$\frac{L_F \left(\left(\frac{h_f(b_n + b_b)}{2} \right) + b_n(h_t - h_f) \right)}{b_n} \times \rho_c + \mu_a$	(3)
μ_F	Mass per unit area of the concrete slab plus additional permanent loads (which is permanent beyond the steel-concrete composite beam and the slab) plus considered percentage of variable / accidental load [Kg/m ²]	$\frac{F_G + F_Q \square \% \varrho_{,RMS\theta} + H_F(b_f + b_b)/2 + b_n(h_t \square h_f)}{b_n} \square r_c$	(4)
μ_V	Linear mass of the steel-concrete composite beam plus permanent loads plus considered percentage of variable/accidental load applied at width corresponding to L_F (distance between beams) [Kg/m]	$L_F (F_G + F_Q \square \% \varrho_{,RMS\theta}) + m_g$	(5)
$f_{1,F}$	Natural frequency of slab influence width [Hz]	$\frac{4}{p} \sqrt{\frac{3(E_{\dot{c}} \square I_y \square \square^9)}{0.3 m_F \square L_F^4}}$	(6)
$f_{1,V}$	Natural frequency of the analyzed pinned-pinned beam represented in Fig. 6 [Hz]	$f_{1,v} = \frac{2}{p} \sqrt{\frac{3(E_{y,c.D.})}{0.9 m \square L_V^4}}$	(7)
f_1	Natural frequency of the system of analyzed beam plus second beam plus slab influence width [Hz]	$\frac{1}{f_1^2} = \frac{1}{f_{1,F}^2} + \frac{1}{f_{1,V}^2} + \frac{1}{f_{1,V,P}^2}$	(8)
$M_{mod,1}$	Modal mass of the analyzed pinned-pinned beam represented in Fig. 6 [Kg]	$0.5 m_V \square L_V$	(9)
M_{mod}	Modal mass of the system of analyzed beam plus second beam plus slab influence width [Kg]	$M_{mod1} \square \frac{L_p}{0.5} \square \frac{0.5}{L_F}$	(10)

Table 4. Variables calculated with their respective equations.

The natural frequency and modal mass of a beam can be determined according to the support conditions. **Equations (7) and (9)** cater to isostatic beams, with symbolic representation in the **Fig. 6**, which will be the ones studied in the building in question.

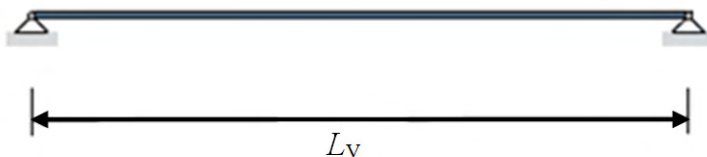


Figure 6. Pinned-pinned beam [personal collection].

There is also an approximation, called Dunkerley's approach, to the natural frequency of a system when performing manual analyzes. It is applied when the shape of the analyzed system mode is complex but it can be divided into single modes for which the natural frequency can be determined. Thus, the natural frequency of a system (f_1 in question) composed of three singular frequencies ($f_{1,F}$, $f_{1,V}$ and $f_{1,V,P}$, described earlier) is obtained by **Eq. (11)**.

$$\frac{1}{f_1^2} = \frac{1}{f_{1,F}^2} + \frac{1}{f_{1,V}^2} + \frac{1}{f_{1,V,P}^2} \quad (11)$$

After determining the natural frequency and modal mass of the system, a damping must be assumed. Such damping may be calculated, irrespective of the method chosen for the calculation of natural frequency and modal mass, by the sum of the damping due to the structure material, to the furniture and to the finishing, as shown in the **Table 5** and in the **Eq. (12)**.

Type	Damping (% of critical damping)
Structural Damping D_1	
Wood	6%
Concrete	2%
Steel	1%
Composite (steel-concrete)	1%
Damping due to furniture D_2	
Traditional office for 1 to 3 persons with separation walls	2%
Paperless office	0%
Open plan office	1%
Library	1%
Houses	1%
Schools	0%

Gymnastic	0%
Damping due to finishes D_3	
Ceiling under the floor	1%
Free floating floor	0%
Swimming screed	1%
Total Damping	
$D = D_1 + D_2 + D_3$	

$$D = D_1 + D_2 + D_3 \quad (12)$$

In the design process, after determine the dynamic characteristics of the slab system (natural frequency, modal mass and damping), the OS-RMS₉₀ value and the acceptance class are obtained. At the diagram corresponding to the damping gathered, both are determined by the intersection of the modal mass value on the x axis and the corresponding natural frequency on the y axis, as shown in **Fig. 1**. Such process can be observed in the flowchart of the **Fig. 7** next.

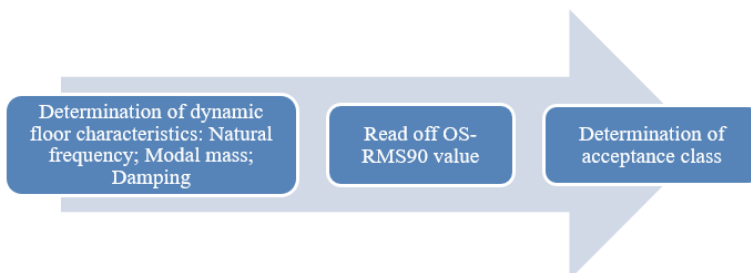


Figure 7. Design process flowchart [personal collection].

3 I CASE STUDY

At the case study, analyzes are performed by numerical modeling via ANSYS® 19.0 Multiphysics, by calculations via Excel and by an experiment of one of the rooms of the NEXEM from UFES. The following are presented the processes and results of those analyses.

The system analyzed is that of the room presented in **Fig. 8**. The dimensions of the beams V3 and V4, indicated in that same figure, and of the room floor slab are exposed in the **Table 6**. The beams parallel to V4 have the same cross-sectional dimensions. Already the specifications of the employed materials, steel and concrete, are displayed in **Table 7**. As for the loads, two analytical assessments are made, the first with the approximate real survey of the permanent and variable forces applied to V4 and the second with the assumption of the load imposed by the designer for these forces on the same beam. The input variable

$f_{i,v,p}$, which represents the frequency of the primary beam (in this case the V3 beams are primary beams) is obtained from numerical modeling next to the experimental analysis, with a subsequent calibration made by analytical calculations. Then the results of f_i , M_{mod} and damping for the V3 + V4 + slab system in each of the two exposed load situations are presented. With values obtained, the acceptance class is determined.

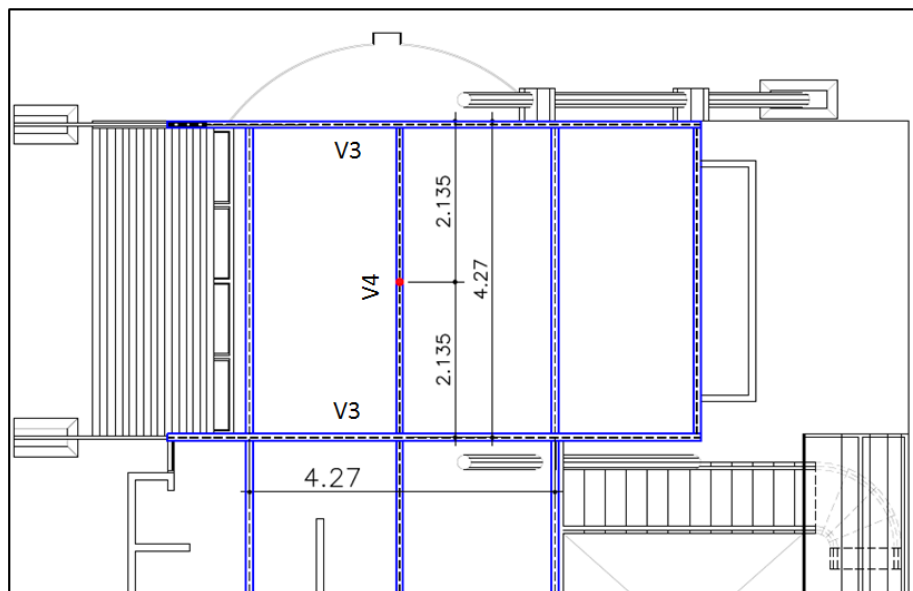


Figure 8. Floor plan of the analyzed room [personal collection].

Beam					
V4		V3		Slab	
Dimension	Value	Dimension	Value	Dimension	Value
$d_{(m)}$	0.2000	$d_{(m)}$	0.3500	$h_t_{(m)}$	0.1100
$b_{f,sup_{(m)}}$	0.1300	$b_{f,sup_{(m)}}$	0.2500	$h_F_{(m)}$	0.0590
$b_{f,inf_{(m)}}$	0.1300	$b_{f,inf_{(m)}}$	0.2500	$b_b_{(m)}$	0.0580
$t_w_{(m)}$	0.0063	$t_w_{(m)}$	0.0095	$b_F_{(m)}$	0.1260
$t_{f,sup_{(m)}}$	0.0080	$t_{f,sup_{(m)}}$	0.0160	$b_n_{(m)}$	0.2100
$t_{f,inf_{(m)}}$	0.0080	$t_{f,inf_{(m)}}$	0.0160		

L_V _(m)	4.2737	$L_{V,P}$ _(m)	4.2700	L_F _(m)	2.1350
----------------------	--------	--------------------------	--------	----------------------	--------

Table 6. Dimensions of structural elements of the system V4+V3+Slab.

Specifications	Value
ρ_a _(kg/m³)	7850
ρ_c _(kg/m³)	2500
f_{ck} _(MPa)	25
f_y _(MPa)	250
f_u _(MPa)	400
E_a _(GPa)	200

Table 7. Material specifications.

3.1 MODEL

The finite element model developed is generated in the *software* ANSYS® 19.0. Steel beams, columns, purlins and bracing structures are modeled with 2-node beam elements (BEAM188) with 6 degrees of freedom (DOF) on each node. The concrete slab is implemented in 8 node solid elements with 3 DOF per node (SOLID185). 4-node shell elements and 6 DOF per node (SHELL181) are used to represent the steel-deck incorporated into the concrete slab. **Figure 9** presents an isometric view of the developed model, on the left, and an enlargement of a section of the structure with the elements chosen to represent each structural component, on the right.

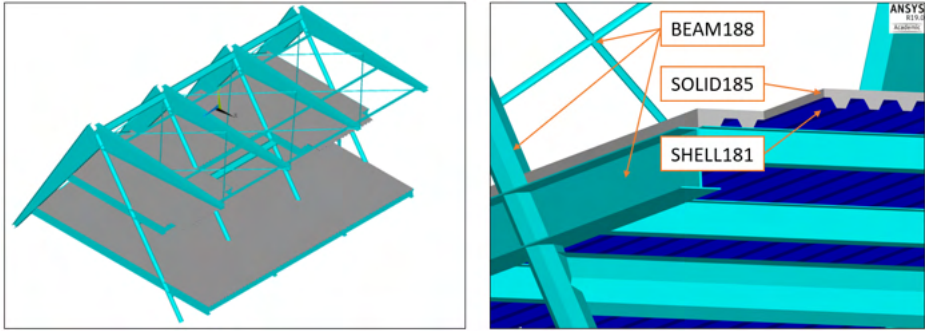


Figure 9. Finite element model developed.

In the modeling is added to the concrete density a value corresponding to the applied overload, found by an approximation of the additional actual total load present during the test plus the permanent load of the ceramic floor covering. It is observed that the other permanent loads of the structure proper weight are already considered in the elements modeled by the program. The assessment of this approximate total additional load is detailed in **Table 8**. To add this value to the concrete density, a conversion is made according to the dimensions of the slab, such conversion is exposed by **Eq. (13)**, whose slab variables are indicated in **Fig. 4**. That slab dimensions are presented in **Table 6**. The result of this process is described at **Table 9**.

Object	Amount [un.]	Unit load [Kg]	Total load [Kg]
Metal cabinet (height \approx 2 meters)	1	32.33	32.33
Metal bookcase (height \approx 2 meters)	6	13.10	78.60
Books by shelf	250	1.30	2600.00
Drawer metal cabinet (height \approx 1.5 meters)	2	23.00	46.00
Books in the drawer cabinets	100	1.30	260.00
Wooden cabinet (height \approx 2 meters)	1	41.30	41.30
Wooden furniture (height \approx 1 meters)	1	19.00	19.00
Wooden desk	2	42.40	84.80
Computer	2	12.00	24.00
Printer	1	12.90	12.90
Common chair	5	10.00	50.00
Swivel chair	2	12.50	25.00
People	4	80.00	320.00
Wood and metal round table	1	23.93	23.93
Sum of total loads (S_c) [Kg]:		3617.86	

Load application area (A_c) [m ²]:	29.15	S_c/A_c [Kg/m ²]:	124.11
		Load of ceramic floor covering [Kg/m ²]:	85
		Additional total charge [Kg/m ²]:	209.11

$$K = \frac{b_n}{((b_m + b_b) \cdot h_f / 2 + (h_t - h_f) \cdot b_n)} \quad (13)$$

Additional load [Kg/m ²]	Correction factor (K) [adm.]	Additional density [Kg/m ³]	Concrete density [Kg/m ³]	Adopted density [Kg/m ³]
209.11	13.01	2721.10	2500.00	5221.10

Table 9. Process results for obtaining the adopted density.

Proper choice of boundary conditions has a great impact on dynamic analysis. However, the representation of boundary conditions of a structure in service is not always as clear as in a computational model. Therefore, so that the results of the developed model are in favor of safety, links that in practice could be considered as semi-rigid, are implemented as flexible. So, to simulate the frame supports, the X, Y and Z axis translations are restricted at the lower end nodes of the pillars. Additionally, hinges are applied between the beam and column nodes whose connections are ideally designed as flexible. **Figure 10** illustrates the boundary conditions (red) and the hinges (green) applied to the developed model.

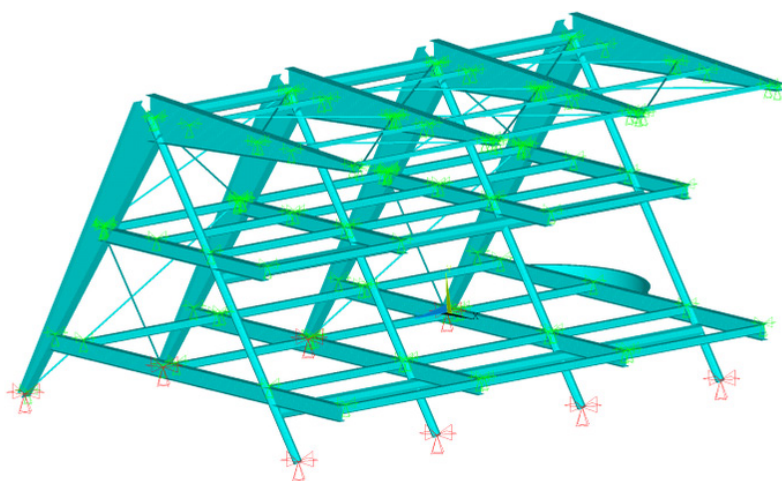


Figure 10. Representation of boundary conditions and hinges applied to the finite element model.

To evaluate the sensitivity of the model to the finite element mesh size adopted, 39 free vibration analyzes are performed for different mesh densities. The number of model elements varies from 37194 elements to 765287 elements. The variable selected for the mesh study is the first natural frequency found in a modal analysis. The optimal mesh is determined considering a maximum percentage error of 1.5% in relation to the result with the most refined mesh. Thus, a mesh with 297999 elements (5873 BEAM188 elements, 89006 SHELL181 elements and 203120 SOLID185 elements), with an average element size of 100 mm, is considered optimal. **Figure 11** presents the results of the mesh strength study by means of a curve with the number of elements *versus* the first natural frequency obtained.

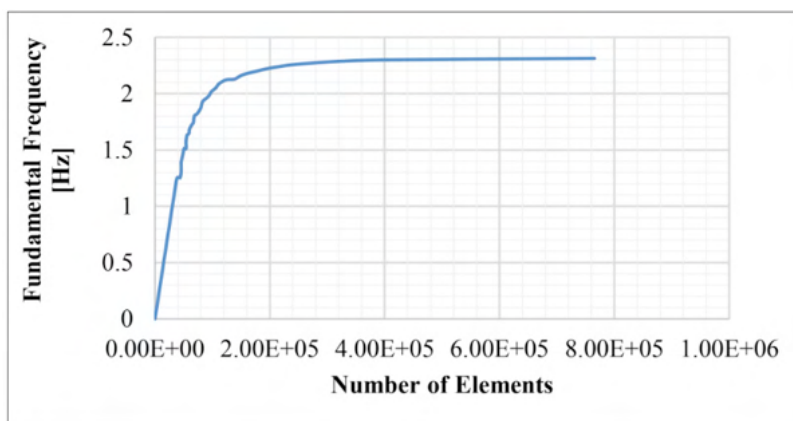


Figure 11. Sensitivity study of the finite element mesh in terms of number of elements *versus* the first natural frequency obtained [personal collection].

Remark 1: Analysis of modeling results to obtain natural frequencies $f_{1,V,P}$ of the primary beams V3. To obtain the natural frequencies $f_{1,V,P}$ of V3 it is performed an analysis of the vibration modes of the model structure made in ANSYS®. 280 vibration modes with frequencies ranging from 0 Hz to 30 Hz are analyzed. The following **Fig. 12** shows the frequencies of the modes in which the vibrations in the studied slab are most noticeable along with the illustration of their respective vibration modes. From the analytical calculations, the natural frequency of 12.46 Hz for the V4 beam is obtained according to the considerations presented in the **Remark 2** and of =13.90 Hz according to the considerations set out in **Remark 3**. Thus, the value **a)** of Fig. 12 is discarded to the natural frequency of V3. With the values presented in the experimental result in **3.2**, the values of **b)**, **c)** and **d)** of **Fig. 12** are possible natural frequency values for V3 primary beams.

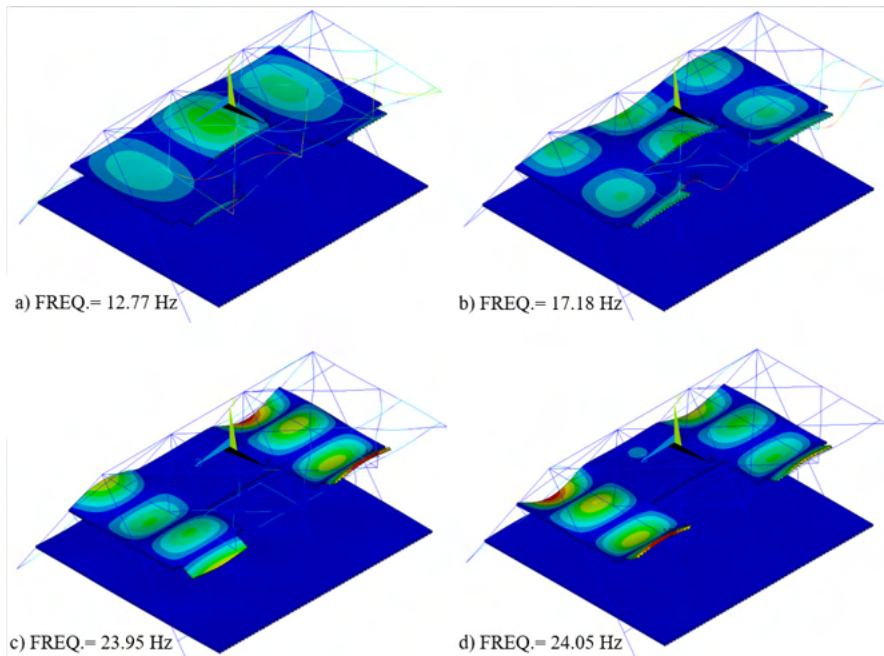


Figure 12. Vibration mode frequencies where the vibration of the studied slab is most noticeable [personal collection].

Remark 2: Analysis with approximated data collection of the real loads.

The data collection of the real loads to obtain the permanent force, F_G , and the variable force, F_Q , applied to V4 is detailed in **Table 10**. Considering that the structure's self-weight (beam plus slab) is already considered in the calculation through other variables, the value of the permanent force, F_G , considers only the load of the ceramic floor covering. For the data collection of the real loads 100% of F_Q are applied, so $\%F_{Q,RMS90}$ equals 100%. With this data, $f_{1,V}$ 12.46 Hz is obtained as the natural frequency value of beam V4.

Variable loads acting on V4	Load [Kg]
Wooden cabinet (height \approx 2 meters)	41.30
Drawer metal cabinet (height \approx 1.5 meters)	23.00
Wood and metal round table	11.97
Common chair	25.00
Metal bookcase (height \approx 2 meters)	26.20
Books by shelf	975.00
Books in the drawer cabinets	130.00
People (4 people)	320.00
Total	1552.47

Permanent loads acting on V4	Load [Kg]
Ceramic floor covering	775.57
Dimensions of application area of loads acting on V4	Value [m]
L_V	4.27
L_F	2.14
Resulting forces	Value [kg/m ²]
F_G	85
F_Q	170.15

Table 10. Approximated data collection of the real loads to obtain F_G and F_Q .

Remark 3: Analysis with the assumption of the loads imposed by the designer.

Assuming the loads imposed by the designer on the V4 beam, F_G equals 85 kg/m², equivalent to the ceramic floor covering load, F_Q equal to 300 kg/m², equivalent to the minimum vertical load value for establishments that received public by NBR 6120:2000 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2007), $\%_{FQ,RMS90}$ and equal to 40%, being considered as the effective combination factor for variable actions caused by the use and occupation, in almost permanent service combinations, for places where there is a predominance of weights and equipment that remain fixed, as exposed by NBR 8800:2008 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008). With this data, $f_{1,V}$ 13.90 Hz is obtained as the natural frequency value of beam V4.

3.2 EXPERIMENT

For the performance of the vibration test, the equipment represented in **Fig. 13** are used. They consist of three to four main items, which are an excitation mechanism to make the analyzed structure vibrate, in the case of the figure represented by an impact hammer; transducer equipment for measuring the parameters of interest; an analog to digital (A/D) converter exposed in **Fig. 14**, for transforming continuous time signals (analog signals) from transducers into discrete signals (digital signals); and a computer system, whose storage unit can be used to store and postprocess the data from the transducers, extract the modal parameters, animate the vibration modes, among other functions.

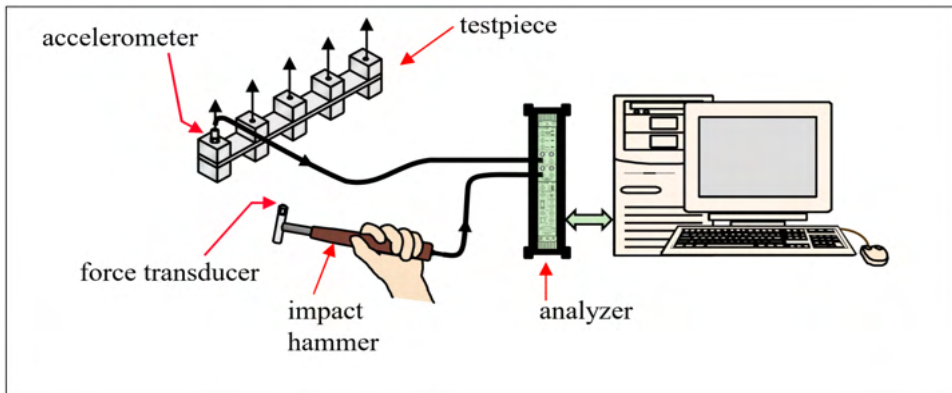


Figure 13. Experimental Setup Where Impact Hammer is Used for Excitation (BILOSOVÁ, 2011).

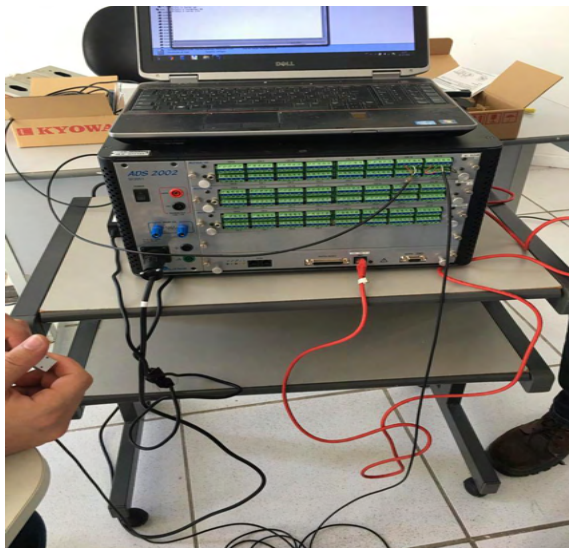


Figure 14. Analog to digital converter (A/D) [personal collection].

In the preparation of the test, the equipment and the type of excitation are chosen. The structure, the points of the structure at which measurements are made and the mechanisms for measuring excitation and response are described. The equipment chosen for the perception of the data is two accelerometers and the vibration is induced by the dynamic actions of 4 people of approximately 80 kg each. The excitation input in turn is not measured in this experiment, but it can be assumed. The structure of the room tested is shown in **Fig. 8** and the points where measurements are taken are shown in **Fig. 15**, on the left. Channels 14 and 15, shown in this figure, represent each of the two accelerometers, which are positioned on the bottom flange of beam V4, at opposite sides to the profile web. Both are fixed with clamps, as shown in **Fig. 15**, on the right.

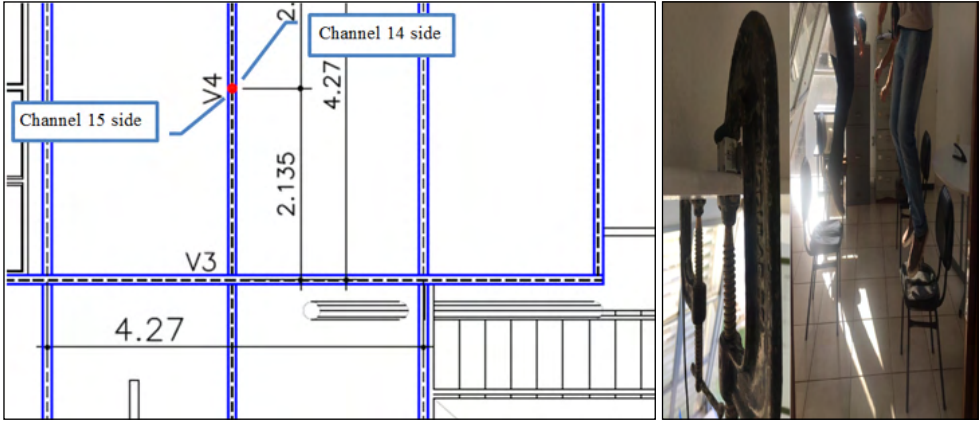


Figure 15. Position of accelerometers in the structure (left) and its fixation under the slab (right) in test [personal collection].

For the experimental analysis, the steel-concrete composite slab under study is instrumented to obtain velocity and acceleration kinematic values. On the bottom flange of beam V4 are placed two accelerometers, one representing channel 14 and the other channel 15, whose positions are shown in **Fig. 15**. The acceleration values as a function of time obtained are treated and the resulting graphs are presented in **Fig. 17**. The peak frequencies of these graphs represent possible natural frequency values of the structural elements, beams V3 or V4, or even another element of the analyzed system. For channels 14 and 15, the angular frequencies of 115 rad/s and 156 rad/s are highlighted for the peaks highlighted by the circumferences in **Fig. 16**. Calculating these frequencies in Hz, they correspond to, respectively, 18.30 Hz and 24.82 Hz.

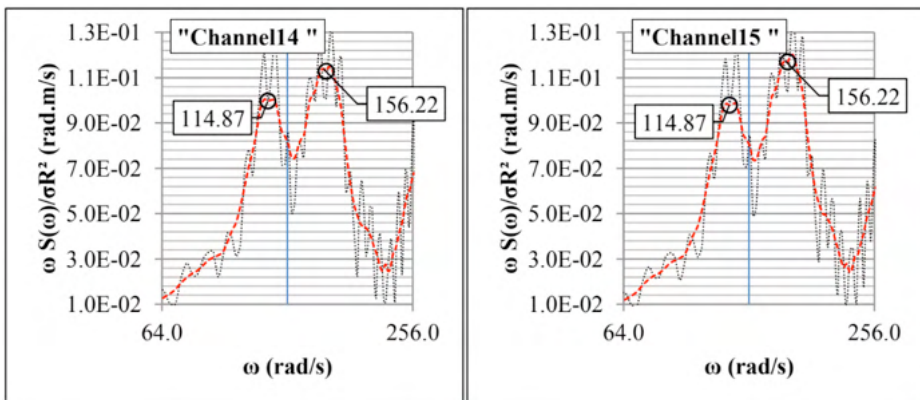


Figure 16. Spectral density in function of frequency, from data from channel 14 (to the left) and 15 (to the right) [personal collection].

4 | DISCUSSION

4.1 COMPARISON (MODEL X EXPERIMENT)

Both natural frequency values measured with the accelerometers are slightly larger than the calculated values shown in **Fig. 12 b**), **c**) and **d**), concerning the natural modes of vibration of the floor beams V3. This increase was 6.5% for the first case (18.30 Hz compared to 17.18 Hz) and 3.5% for the second case (24.82 Hz compared to 23.95 Hz).

Such an increase may be partially explained by one of the phenomena studied by Kim et al. [3] in natural frequency analysis of horizontal vibration of tall buildings, in this case the aging of concrete. Kim et al. [3] and Ferrareto (FERRARETO, 2018) found significant increases in the natural frequencies of structures after considering this effect. The values found by the authors were, respectively, 0-4% and 3-5%.

4.2 MODEL CALIBRATION

According to NBR 6118:2014 (ABNT, 2014), The modulus of elasticity for concrete aging can be described by **Eq. (14)** below:

$$E_{Ci,\infty} = \lim_{t \rightarrow \infty} E_{Ci,28} \{ \exp \{ s [1 - (28/t)^{0.5}] \} \}^{0.5} = E_{Ci,28} \exp(s/2). \quad (14)$$

Where:

$E_{Ci,28}$: Young's Modulus of concrete after 28 days, as NBR 6118-2014;

t : Represents the age of the concrete, in days, here considered to be physically infinite;

s : Coefficient dependent on the cement category (in the structure analyzed in chapter 3, it assumes the value of 0.25);

$E_{Ci,\infty}$: means Young's Modulus of matured concrete: probable \mathcal{E} .

Considering the above hypotheses, for calculation purposes in *Service Limit State only*, the modulus of elasticity of the concrete according to **Eq. (15)** assumes a value 13% higher. Thus, by introducing this new value of $E_{Ci,\infty}$ in the beam calculations, it has:

$$E_{Ci,\infty} = 1.13 E_{Ci,28}. \quad (15)$$

Thus, the natural frequency presented in the **Fig. 12 b**) assumes the value 18.07 Hz and those shown in the **Fig. 12 c**) e **d**) assume the value 25.15 Hz. The primary beam V3 of the bottom part of **Fig. 8** assumes the natural frequency value of 18.07 Hz and that of the top part of the same figure assumes the natural frequency of 25.15Hz. Values and assignments provided by analytical calculations, which approximate the results of the modeling. From this, four vibration comfort ratings are made, as shown in **Fig. 17**. Diagram I of this figure considers

the data $f_{1,V} = 12.46$ Hz (relative to V4 for real loads) and $f_{1,V,P} = 18.07$ (relative to V3 from the bottom of **Fig. 8**). Diagram II considers the data $f_{1,V} = 12.46$ Hz (relative to V4 for actual loads) and $f_{1,V,P} = 21.15$ Hz (relative to V3 from the top of **Fig. 8**). Diagram III considers the data $f_{1,V} = 13.90$ Hz (relative to V4 for design loads) and $f_{1,V,P} = 18.07$ Hz (relative to V3 from the bottom of **Fig. 8**). Diagram IV considers the data $f_{1,V} = 13.90$ Hz (relative to V4 for design loads) and $f_{1,V,P} = 25.15$ Hz (relative to V3 from the top of **Fig. 8**). These and other data considered in the classifications are shown in **Table 11**. The diagrams presented consider a 4% damping. That damping is obtained considering the room in study made of a steel-concrete composite structure, being a traditional office for 1 to 3 people with separation walls and with ceiling under the floor, following **Table 5**. The recommendation presented on **Table 11** is for an application on spaces for education use.

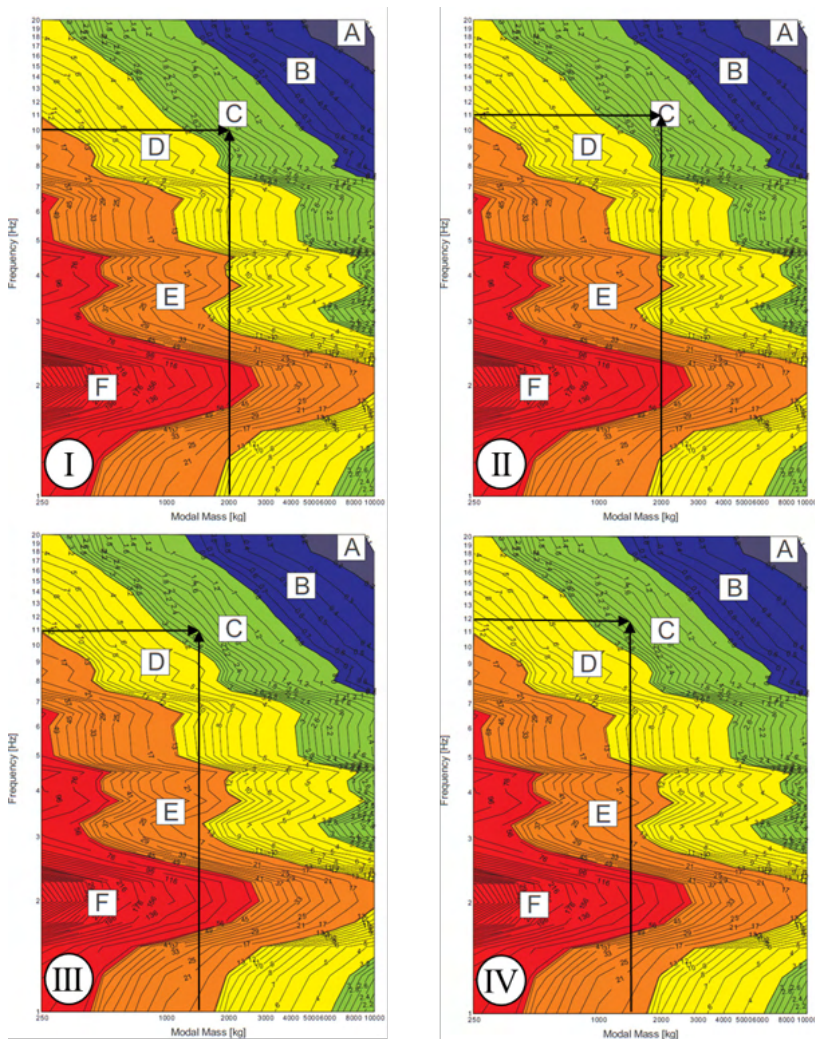


Figure 17. Diagrams for the vibration comfort classifications.

Diagram	$f_{1,F}$ (Hz)	$f_{1,v}$ (Hz)	$f_{1,v,p}$ (Hz)	f_1 (Hz)	$M_{mod,1}$ (kg)	Class	Recommendation
I	81,6	12,46	18,07	10,18	2095	C	Recommended
II	81,6	12,46	25,15	11,06	2095	C	Recommended
III	91,3	13,9	18,07	10,94	1684	C	Recommended
IV	91,3	13,9	25,15	12,06	1684	C	Recommended

Table 11. Data considered in the classification.

4.3 STANDARD APPRAISAL

Following item 11 and annex L of NBR 8800: 2008 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008), vibration-susceptible flooring systems, such as areas without damping mechanisms, must be dimensioned so as to avoid the appearance of unacceptable vibrations due to walk from people or other sources. This fact includes the room under study.

According to Annex L, the natural frequency of the floor structure cannot be less than 3 Hz. In modeling, the first mode of vibration of the slab structure under study, illustrated in **Fig. 18**, is 9.72 Hz. For simplified analysis exposed in NBR 8800:2008 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2008), on floors where people walk regularly, which includes the room under test, the lowest natural frequency cannot be less than 4 Hz or, in some cases, 3Hz, which is vaguely described. However, the standard also suggests a static analysis of deflection. The standard says that this condition is satisfied if the total vertical displacement of the floor caused by permanent actions, excluding the time-dependent portion, and by variable actions, calculated by considering the beams as pinned-pinned and using the frequent service combinations given in section 4 of this same standard, do not exceed 20 mm. This value is calculated and 5.2 mm vertical displacement is obtained for V4 with the design loads, which is enough for design acceptance.

However, one may notice that the frequency values of 4 Hz and 9.72 Hz and the displacement values of 5.2 mm and 20 mm used for normative classification are relatively distant. These circumstances expose that the structure analyzed passes the vibration evaluation with a much larger clearance in the analysis by NBR than by the comfort analysis proposed on this paper and illustrated in **Fig. 17**.

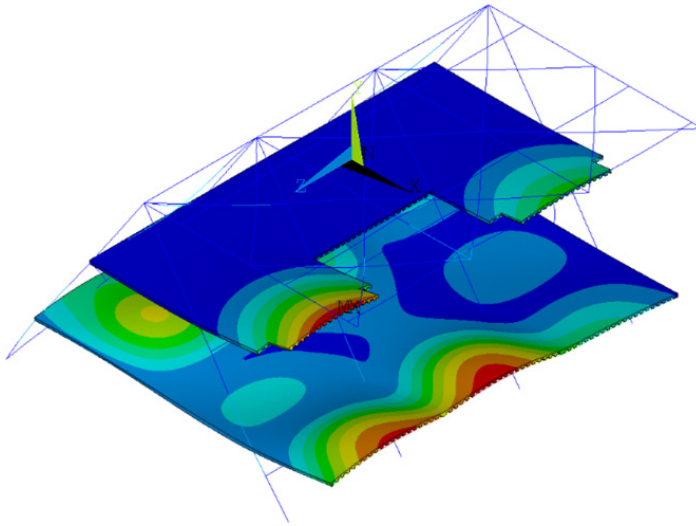


Figure 18. First vibration mode of the slab in study.

4.4 OCCUPANT COMFORT QUESTIONNAIRE

A questionnaire to assess the vibration comfort of the structure studied is delivered to the occupants of NEXEM. The questionnaire is answered by 15 occupants, of whom 5 are under 30 years old, 6 are between 30 and 40 years old, 3 are between 40 and 60 years old and 1 is over 60 years old. This analysis is exposed as age influences the perception of discomfort that may be caused by vibrations. Amongst the 15 people, 4 declared the vibration of the building irritating or annoying, most often once every two weeks. 3 people even find the vibration disturbing or frightening, as shown in **Fig. 19**, most often once every 6 months, especially on the ramp and stairs of the building. 5 people find the vibration most noticeable when they are less busy. Variations in personal thermal sensations do not appear to influence the perception of vibrations. None of the occupants answering the questionnaire has ever made a complaint about vibration, but 3 of the respondents imagine them making that in the future.

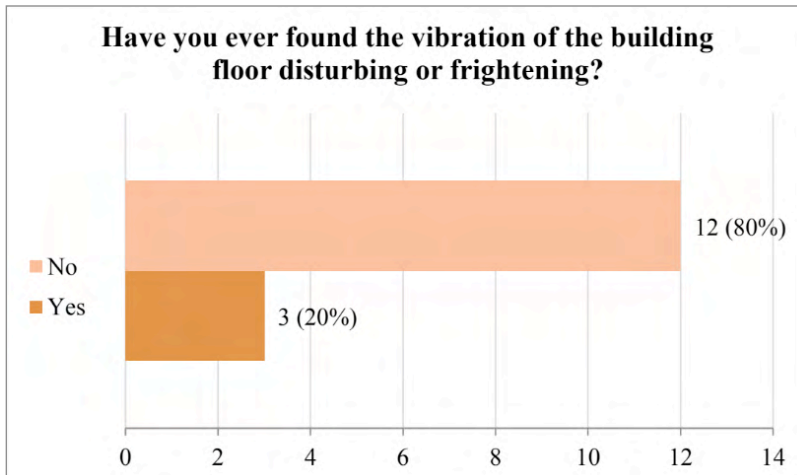


Figure 19. Twenty percent of the people questioned find the vibration disturbing or frightening.

5 | CONCLUSIONS

Considering the results presented by the questionnaire, it is possible to say that the vibration in the building of the NEXEM is noticeable and can be annoying or even frightening. Through the vibration comfort classification obtained and exposed in the diagrams of **Fig. 17**, it is clear that the chart assessments are very close to class D, which is considered critical for floors with educational function. However, the analysis made by building code NBR 8800:2008 shows a situation that is quite far from critical, as explained in **4.3**. From these facts, it is essential to evaluate a metallic or a steel-concrete composite structure considering the complete dynamic characteristics of the structure, as performed in **4.2**.

ACKNOWLEDGEMENTS

The authors would like to thank the Federal University of Espírito Santo and the Arcelor Mittal Brazil Research and Development team, as well as all others involved, who contributed in some way to the achievement of the results presented in this paper.

REFERENCES

ABNT. ABNT NBR 6118:2014 - Projeto de estruturas de concreto — Procedimento. **Associação Brasileira De Normas Técnicas**, p. 238, 2014.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 6120: Cargas para o cálculo de estruturas de edificações**. . [S.l.: s.n.] , 2007.

_____. **NBR 8800: Projeto de estruturas de aço e de estruturas mistas de aço e concreto de edifícios 2 ed.** . Rio de Janeiro, Brasil: [s.n.] , 2008.

BILOSOVÁ, Alena. **Modal Testing**,. . VŠB TU Ostrava: [s.n.], , 2011.

FELDMANN, Markus; HEINEMEYER, Christoph; VOLLING, B. **Design Guide for Floor Vibrations - ArcelorMittal. Built Environment**. Esch-sur-Alzette, Luxembourg: [s.n.], , 2008.

FERRARETO, Johann Andrade. Impact of structural design criteria on the comfort assessment of tall buildings. **Journal of Wind Engineering and Industrial Aerodynamics**, v. 180, n. February, p. 231–248, 2018.

ISO 10137. **Bases for design of structures - Serviceability of buildings and walkways against vibrations 2 ed.** . Geneva, Switzerland: INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 2007.

KIM, Ji Young et al. Calibration of analytical models to assess wind-induced acceleration responses of tall buildings in serviceability level. **Engineering Structures**, v. 31, n. 9, p. 2086–2096, 2009. Disponível em: <<http://dx.doi.org/10.1016/j.engstruct.2009.03.010>>.

SEDLACEK, G et al. **Generalisation of criteria for floor vibrations for industrial, office, residential and public building and gymnastic halls.** . Luxembourg: [s.n.], , 2006.

SETAREH, M.; LOVELACE, M. Vibration analysis and design of a structure subjected to human walking excitations. **Shock and Vibration**, v. 17, n. 4–5, p. 631–639, 2010.

ÍNDICE REMISSIVO

A

Acoplamento termomecânico 44, 48, 52

Algoritmo genético (AG) 244

Alvenaria estrutural 4, 44, 48

Análise de imagem 235, 240, 241

Aprendizado de máquina 2

Arduino 17, 18, 19, 20, 141, 142, 144, 145, 146, 147, 148, 152, 154, 157, 158, 159, 160, 161

Arquitetura de software 5, 74, 75, 76

B

Balanced spaces 34

Biblioteconomia clínica 21

Bluetooth 141, 142, 143, 144, 146, 147, 148, 151, 152, 154, 155, 156, 157, 158, 159, 160, 177

C

Cenários arquiteturais 5, 74, 87

Ciclo de vida arquitetural 74, 76, 77, 85, 87

Comunicação científica 3, 5, 57, 58

Conjuntos de similaridade 5, 105, 107, 108, 116

Correlação 235, 236, 240

D

Dados complexos 105, 106, 107, 108

Design science research 57, 58, 59, 62

Desigualdade de gênero na TI 173, 174

Dibujo asistido por computadora 6, 162, 163, 164, 171

E

Educación a distancia 162, 164, 165, 168, 170, 171

Elementos finitos 3, 48, 52, 53, 223

Energia renovável 185

Equivalência de funções 6, 118

F

Fibra de carbono 223

G

Gêmeo digital 5, 63, 64, 68, 71

Grafos 105, 112, 259, 261

H

Herramientas tecnológicas 6, 162, 163, 164, 170

Histórico feminino na TI 173, 174

Human comfort 198

I

Identificação de sistemas 185, 188, 189

Idosos 16, 17, 20

Indústria 4.0 63, 65, 66, 67

Infecções por Coronavirus 2

Interoperabilidade 21, 23, 24, 25, 26, 30, 32, 63, 64, 66, 67

J

JavaCV 235, 236, 237, 240, 241

JavaScript 141, 142, 153, 263

L

Ligas de alumínio 223

M

Memorandos técnicos 5, 74, 76, 78, 80, 81, 86, 87

Método sem malha local 243, 244

Método sem malha local com integração reduzida (ILMF) 244

Métrica de distância 5, 105, 113, 116

Microcontrolador 17, 141, 152

Mixed finite elements 34

Mulheres na TI 173, 174, 182, 183

Mulheres nos cursos superiores de TI 173, 174

O

Ontologias 21, 22, 23, 24, 25, 29, 30, 31, 32

opencv 241

OpenCV 235, 236, 237, 240, 241

Optimal detailing 89

P

Poisson's equation 34, 36

Prestressed concrete 89, 90, 91, 92, 96, 103

R

Rami 4.0 65

RAMI 4.0 63, 64, 65, 66, 67, 68, 69, 71

Realidade aumentada 3, 5, 57, 58, 60, 62

Remédios 3, 4, 16, 17, 20

Resistência ao fogo 44, 45, 49, 50, 56

Resistência mecânica 50, 55, 223

Robotista 63

S

Sistemas ciberfísicos (CPS) 63, 64, 71

Static condensation 4, 34, 35, 36

Steel-concrete 6, 198, 199, 200, 202, 204, 205, 206, 216, 218, 221

T

Terminologias clínicas 4, 21, 23, 24, 25, 30

Teste de hipótese 105

U

Usinas eólicas 185

V

Vibrations 6, 198, 199, 212, 219, 220, 222

Visões do modelo 4+1 5, 74, 87

Visualização de dados 57

W

Wi-Fi 141, 142, 147, 148, 152, 153, 157, 158

COLEÇÃO

DESAFIOS DAS ENGENHARIAS:



ENGENHARIA DE COMPUTAÇÃO 3

-  www.atenaeditora.com.br
-  contato@atenaeditora.com.br
-  [@atenaeditora](https://www.instagram.com/atenaeditora)
-  www.facebook.com/atenaeditora.com.br

COLEÇÃO

DESAFIOS DAS ENGENHARIAS:

ENGENHARIA DE COMPUTAÇÃO 3

-  www.atenaeditora.com.br
-  contato@atenaeditora.com.br
-  [@atenaeditora](https://www.instagram.com/atenaeditora)
-  www.facebook.com/atenaeditora.com.br