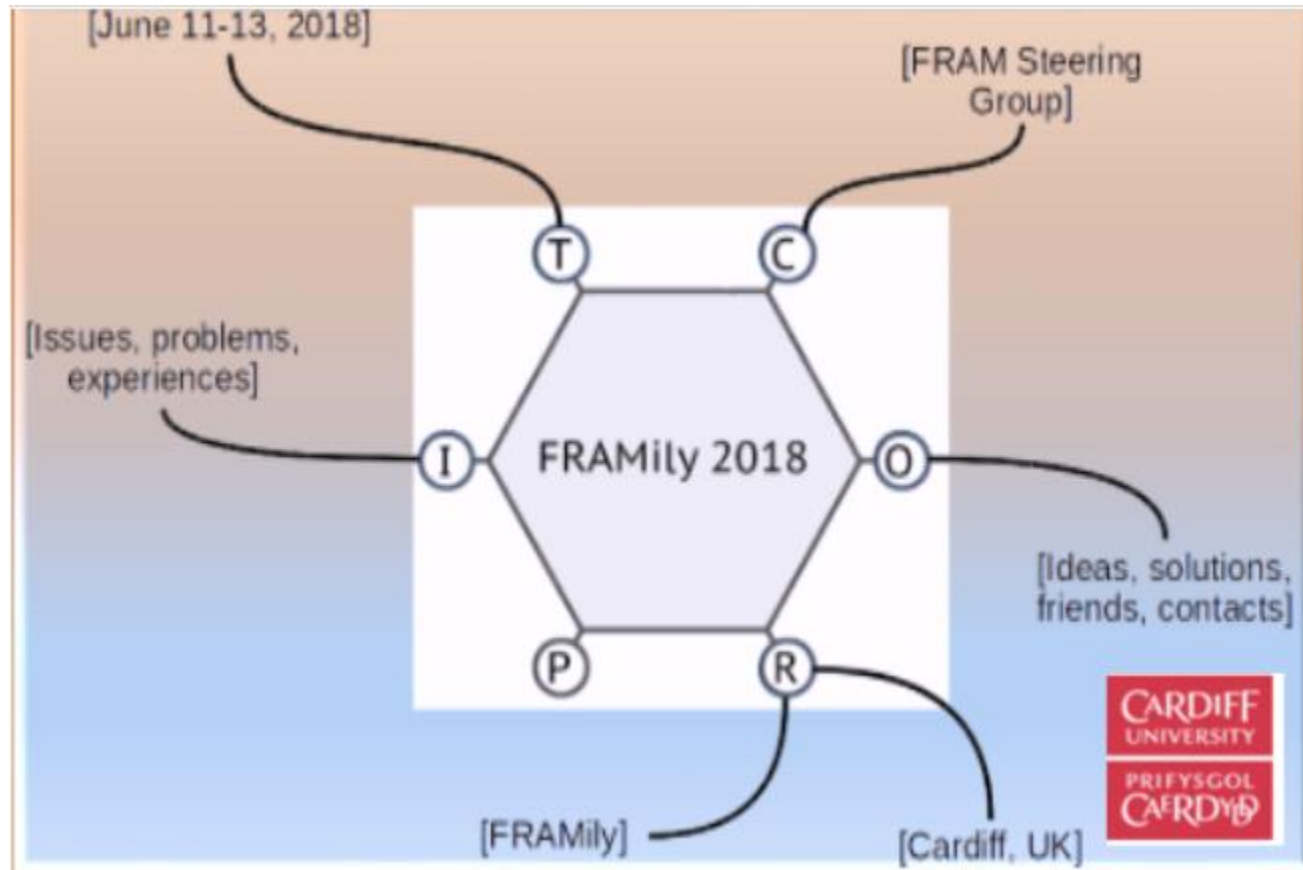


The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

Article in JSDEWES

(Journal of Sustainable Development of Energy, Water and Environment Systems)

A Resilience Engineering Approach for Sustainable Safety in Green Construction

Authors

Lucio Vilarinho Rosa, DSc

Josué Eduardo Maia França, MSc

Assed Naked Haddad, DSc

Paulo Victor Rodrigues de Carvalho, DSc



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales



*Journal of Sustainable Development of Energy, Water
and Environment Systems*

<http://www.sdewes.org/jsdewes>



Year 2017, Volume 5, Issue 4, pp 480-495

A Resilience Engineering Approach for Sustainable Safety in Green Construction

Lucio V. Rosa¹, Josué E. M. França², Assed N. Haddad³, Paulo V. R. Carvalho^{*4}

¹Estácio de Sá University, Avenida das Américas, 4200, Rio de Janeiro, Brazil

e-mail: villavr@poli.ufrj.br

²Fluminense Federal University, R. Miguel de Frias 9, Icaraí, Niterói, 24220-900,
Rio de Janeiro, Brazil

e-mail: josue.maia@poli.ufrj.br

³Federal University of Rio de Janeiro, Av. Pedro Calmon 550, Cidade Universitária, 21941-901,
Rio de Janeiro, Brazil

e-mail: assed@poli.ufrj.br

⁴Nuclear Engineering Institute, Cidade Universitária, R. Hélio de Almeida 75, Ilha do Fundão, 21941-614,
Rio de Janeiro, Brazil

Federal University of Rio de Janeiro, Av. Pedro Calmon 550, Cidade Universitária, 21941-901,
Rio de Janeiro, Brazil

e-mail: paulov195617@gmail.com

The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

This article is characterized by a **combined study of FRAM-AHP** and its decision-making process for risk analysis of a specific sustainable reconstruction activity of Maracanã stadium in Brazil.

AHP is featured for its multi-criteria decision-making methodology, constituted by a mathematical structure that are in fact a simulation of human mental **decision-making**, which can complement the utilization of FRAM in **complex socio-technical systems**.

In another hand, FRAM is a methodology that define the couplings among various functions of a complex system in a dynamic way. Seeking to complement the FRAM, is necessary a **mechanisms that can formalize the decision-making process**.

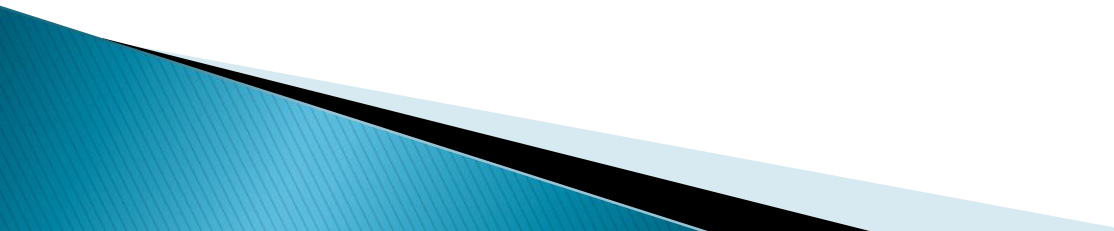
The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

In short, **FRAM** and **AHP** are the main methodologies used by this article to analyze the risks of the **complexity activity of an stadium reconstruction**, focused on the sustainable issues of recycling materials production.

FRAM was chosen because can analyze how **complex activities** take place either retrospectively or prospectively, generating a graphic model of how an activity is done and interacts.

The construction industry is a complex segment and has an **not promising accident history** in Brazil. This scenario **requires an adequate methodology that can deal with this complexity**.



The 12th FRAMily meeting/workshop, June 11th - 13th 2018
Cardiff University, Wales



A word cloud centered around the word "resilience". The word "resilience" is the largest and most prominent, written in a dark blue serif font. Surrounding it are various other words in different sizes, colors (including dark blue, brown, and gold), and orientations. The words include: "safety" (large, brown, top right), "engineering" (medium, brown, top center), "risks" (medium, brown, top left), "methodologies" (medium, brown, middle right), "losses" (medium, gold, middle right), "accident" (large, gold, bottom center), "construction" (medium, brown, bottom center), "civil" (small, brown, above "accident"), "green-construction accidents" (small, brown, bottom right), "sustainable" (medium, brown, bottom left), "environment" (small, brown, below "sustainable"), "human-system" (small, brown, rotated 90 degrees, bottom left), and "incidents" (small, brown, above "construction"). The background is white with a blue and black geometric shape in the bottom left corner.

resilience

safety

engineering

risks

methodologies

losses

accident

construction

Civil

green-construction accidents

sustainable

environment

human-system

incidents

The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales



**Reconstruction
phase**

Today



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

How much this scenario of the sustainable reconstruction of Maracanã stadium is relevant for a safety study using FRAM & AHP?

According with the inspection team of Labor Ministry of Brazil in Rio de Janeiro regional division, during the period of 2013 to 2016, which includes the **reconstruction of Maracanã stadium**, the inspection scenario was:

- **272 inspections at various construction sites in the city;**
- **1.702 infraction notices issued;**
- **43 worksites embargoed or barred;**
- **12 fatal accidents;**
- **5 serious accidents.**

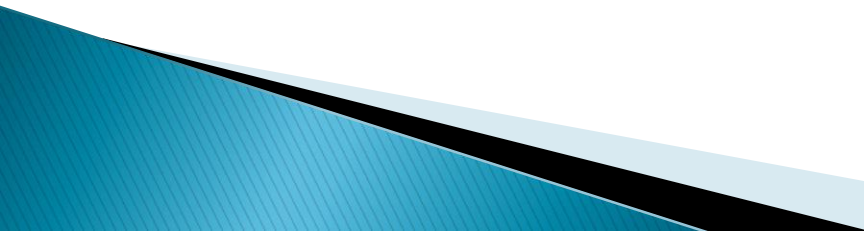
The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

And in this context of multiple risks of Maracanã stadium reconstruction, why use the concepts of **Resilience Engineering** to seek a sustainable safety for green construction?

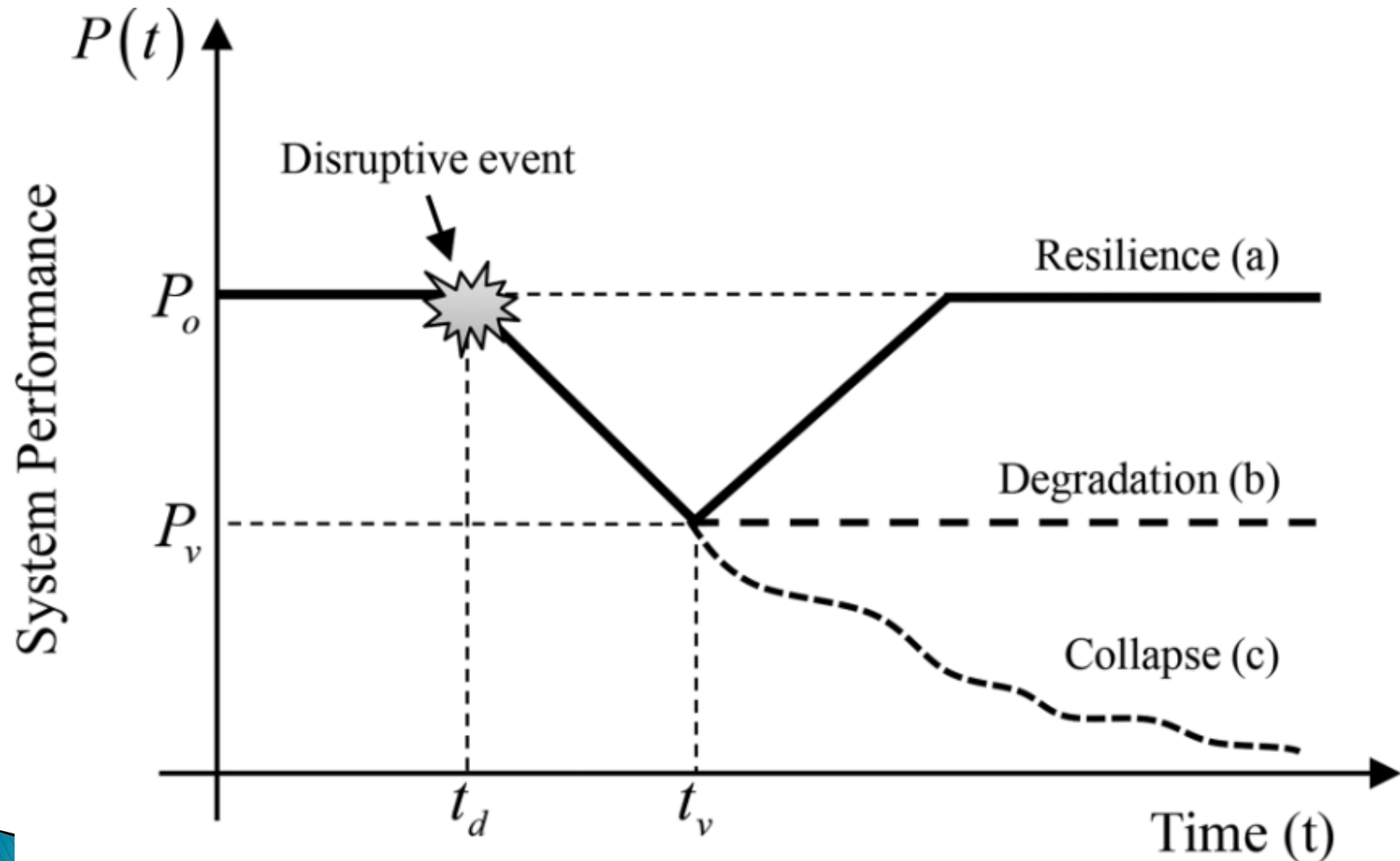
Resilience engineering is a new way for safety management in socio-technical systems. Rather than looking for the causes of an accident, the aim of these new concepts is to **recognize how systems work to develop increased resilient systems.**

For instance, instead of having systems that are not aware of unsafe variabilities, the **resilient systems operate in higher risk levels**, and is able to create safety management systems to identify variabilities to provide adequate answers before accidents occurs.



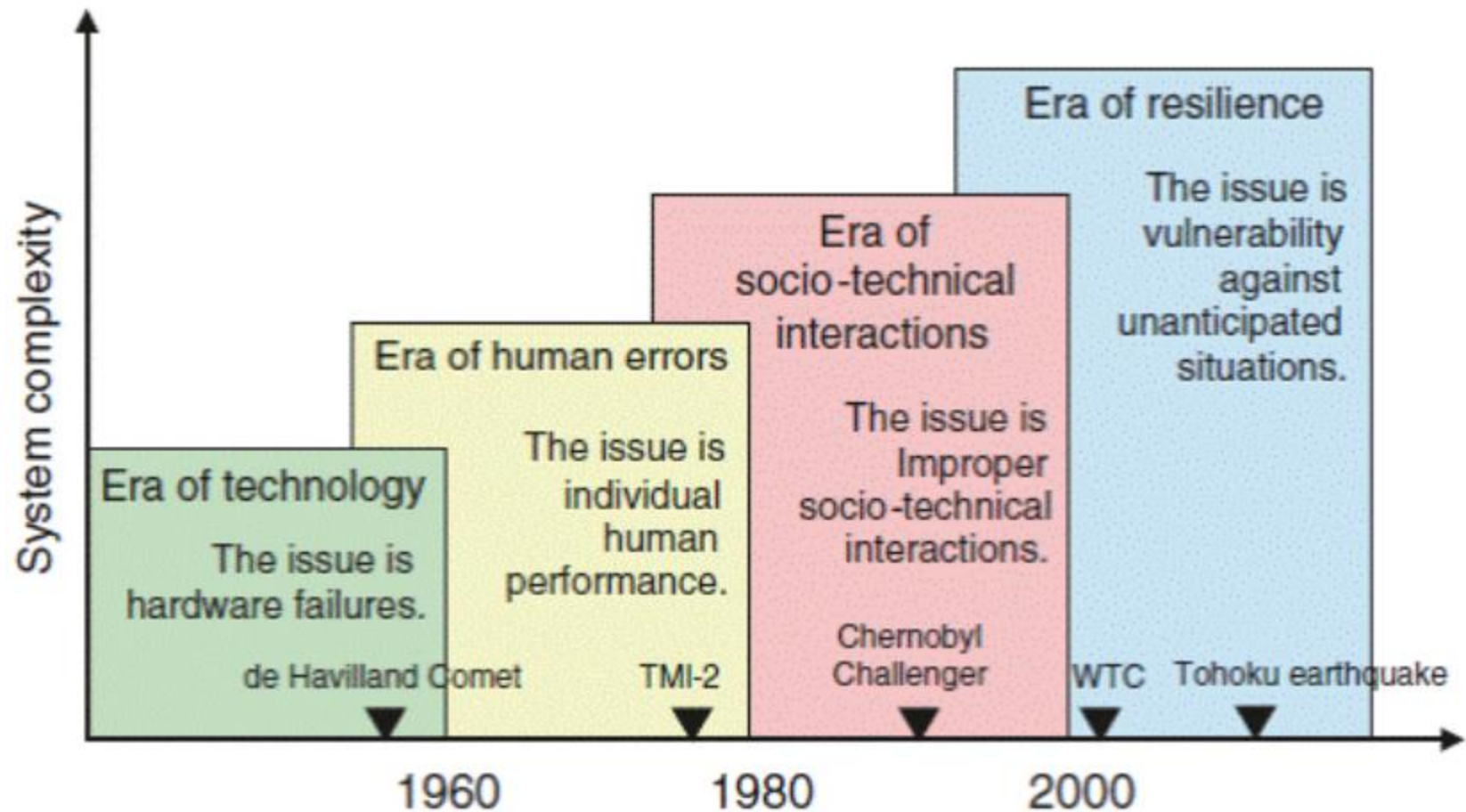
The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales

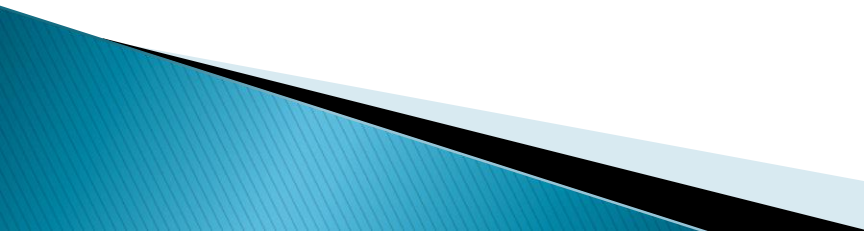


The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

-
1. **respond** to the actual
 2. **monitor** the critical
 3. **anticipate** the possible
 4. **learn** from the factual
-

Resilience engineering seeks to understand the entire process, without focusing on specific faults, because **complex systems usually fail in complex ways.**



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales

And in this context of multiple risks of Maracanã stadium reconstruction, why use **FRAM** methodology combined with **AHP** to seek a sustainable safety for green construction?

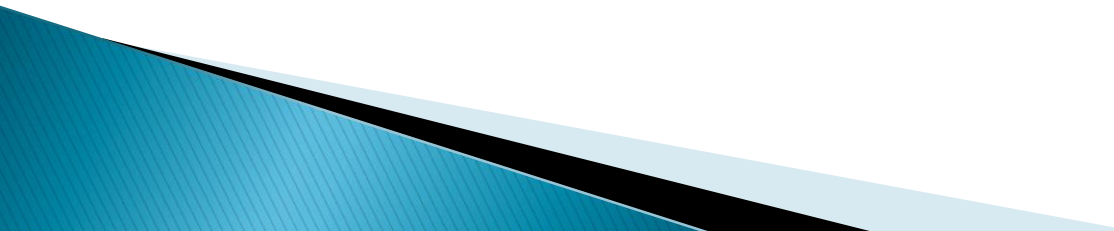
Traditional models of accident investigation and risk analysis are based on chains of events and usually **do not consider the combination of possible variations** in human actions, equipment, organization culture or the interrelations between those.

The **FRAM** is based on resilience engineering principles and concepts, to provide a practical approach aimed to identify how the system functions (or should function) for everything to succeed (i.e., everyday performance), and to understand the variability which alone or in combination may prevent that from happening.

The 12th FRAMily meeting/workshop, June 11th - 13th 2018

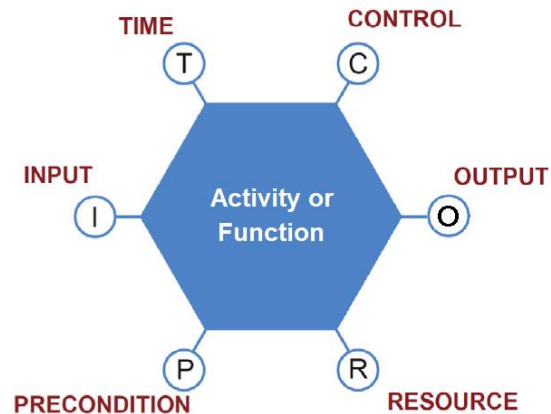
Cardiff University , Wales

The main steps of a FRAM analysis are (Hollnagel, 2012):

- a. Setting the goal for modeling and describing the situation to be analyzed.
 - b. Identifying the main functions of the process, and characterizing them, according to input, output, preconditions, resources, time, and control.
 - c. Characterizing the actual/potential variability of functions.
 - d. Considering both normal and the worst-case variability.
 - e. Defining functional resonances, based on potential/actual couplings among functions.
 - f. Providing ways to monitor and minimize the variability of performance.
- 

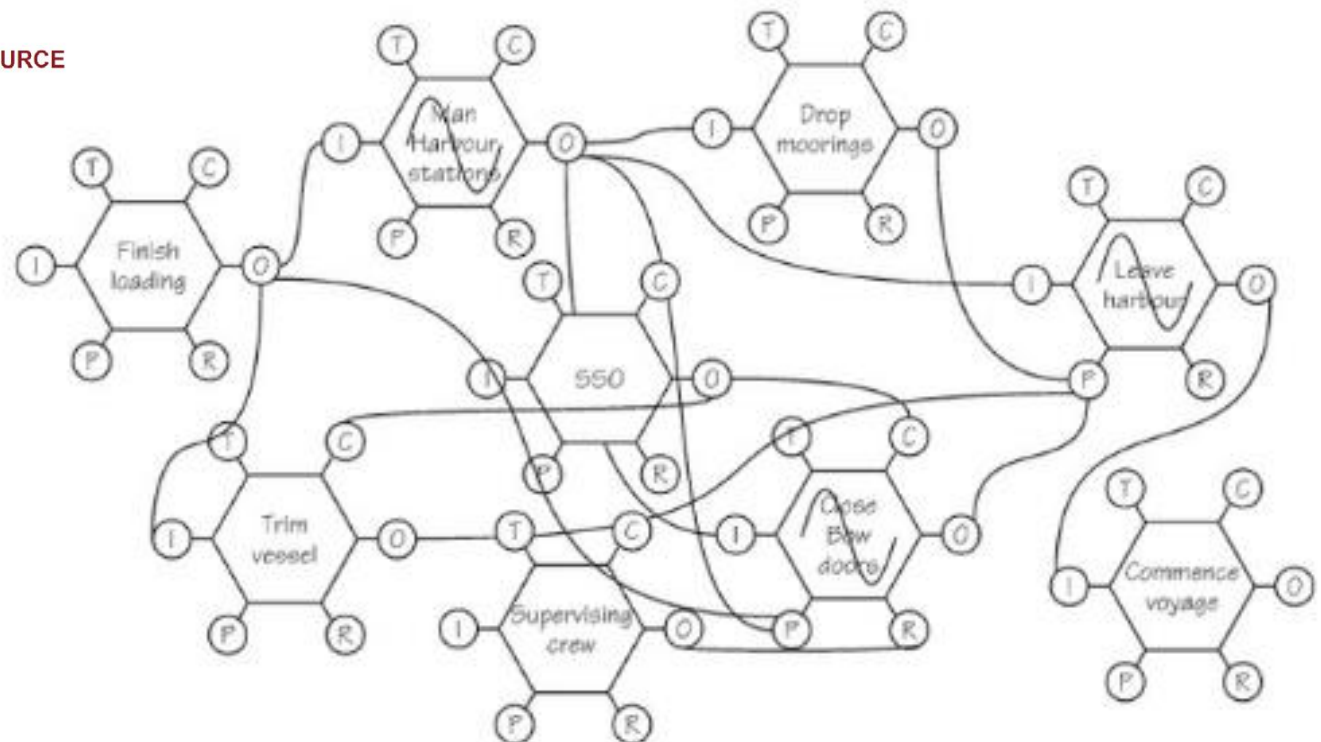
The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales



FRAM

Functional Resonance Analysis Method



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

And how **AHP** can help on this context of Maracanã stadium reconstruction using **FRAM**?

AHP is a structured method to support judgment and decisions in order to minimize the subjectivity in the **characterization of the actual/potential variability of functions** of FRAM.

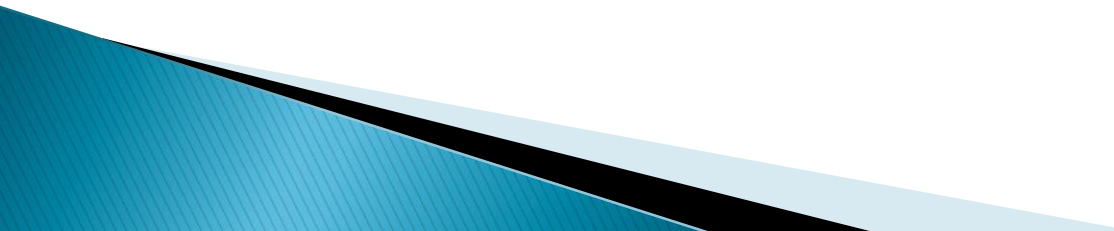
AHP is based on the use of pairwise comparisons that lead to the elaboration of a ratio scale.

Moreover, AHP permits the refinement of the decision-making process, while respecting the global coherence of the answers, by calculating an overall consistency ratio.

The 12th FRAMily meeting/workshop, June 11th - 13th 2018

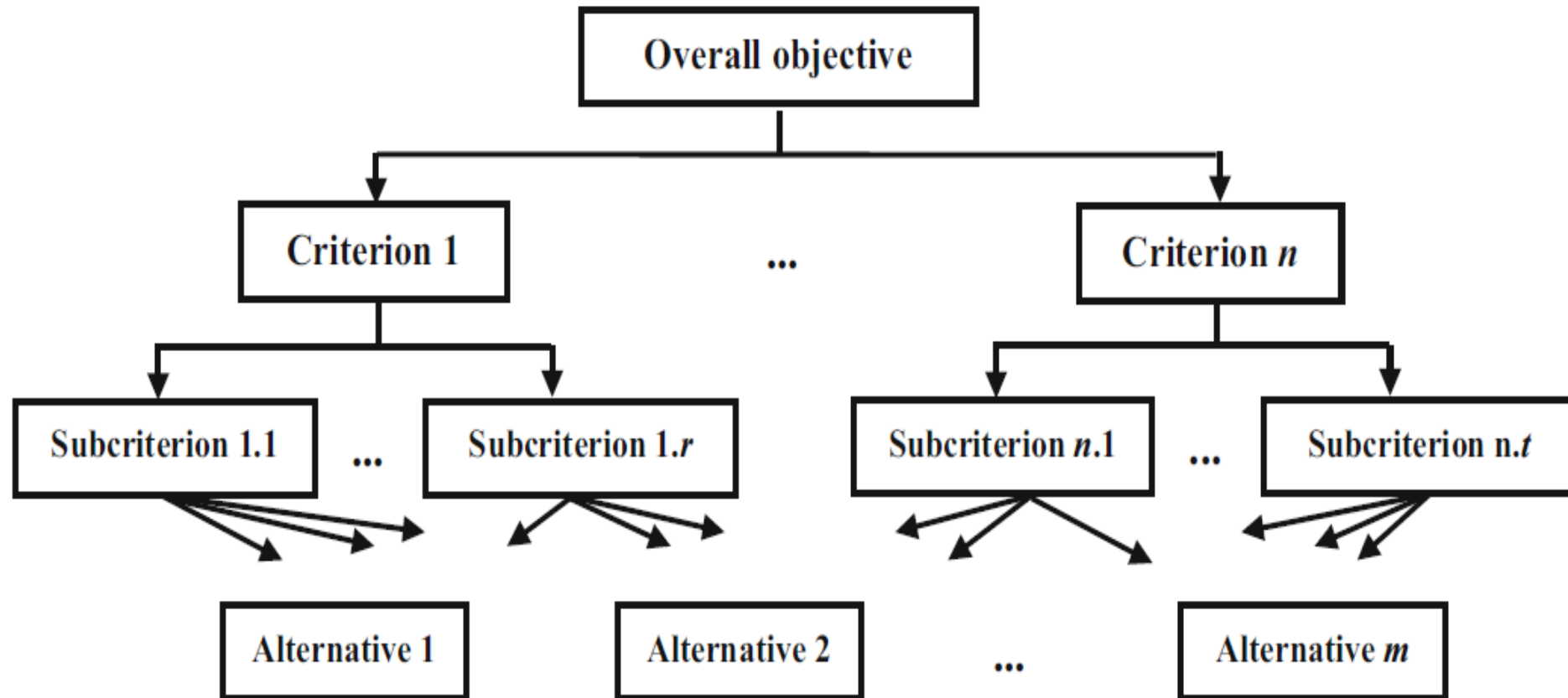
Cardiff University , Wales

The elaboration of an **AHP** is formed by four stages (Saaty 1980):

- a. Structuring the hierarchy in order to identify the main goal, criteria, subcriteria, and alternatives.
 - b. Data collection of value judgments issued by experts.
 - c. Calculating the priority of each alternative.
 - d. Consistency analysis.
- 

The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales

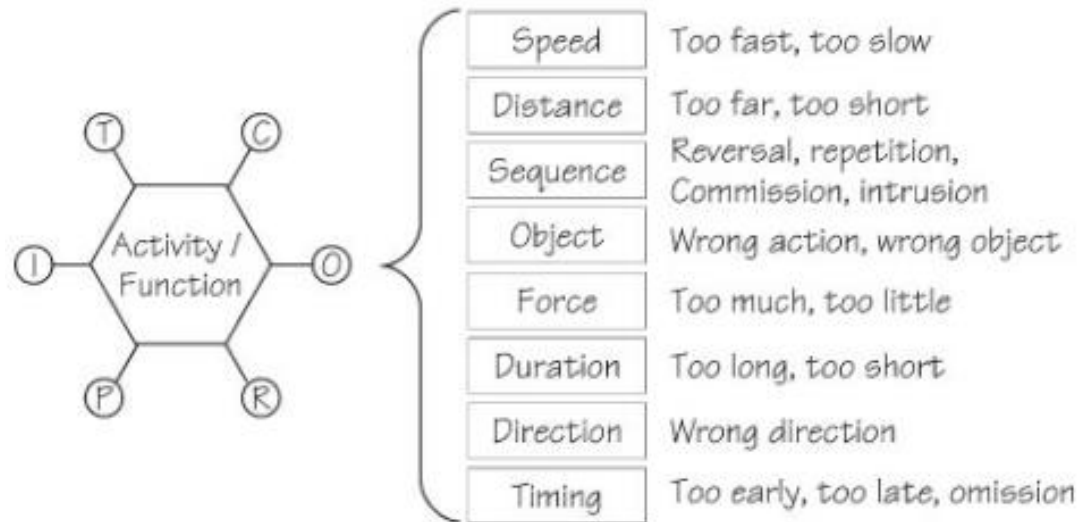


Table 6.4 Possible Output variability with regard to precision

	Precision range of variability of Output		
	Precise	Acceptable	Imprecise
Technological function	Normal, expected	Unlikely	Unlikely
Human function	Possible, but unlikely	Typical	Possible, likely
Organisational function	Unlikely	Possible	Likely

The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales

Judging output variability

1. Knowing the objective of determining the relative importance of phenotypes in relation to output variability, rate the following:

	minor importance				same importance	larger importance				
	extremely	a lot	little	slight		extremely	a lot	little	slight	
Force/distance/direction has										compared to time/duration
Force/distance/direction has										compared to sequence
Force/distance/direction has										compared to wrong object
Time/duration has										compared to sequence
Time/duration has										compared to wrong object
Sequence has										compared to wrong object
	1/9	1/7	1/5	1/3	1	3	5	7	9	

The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

Maracanã reconstruction scenario: recycling process activity.



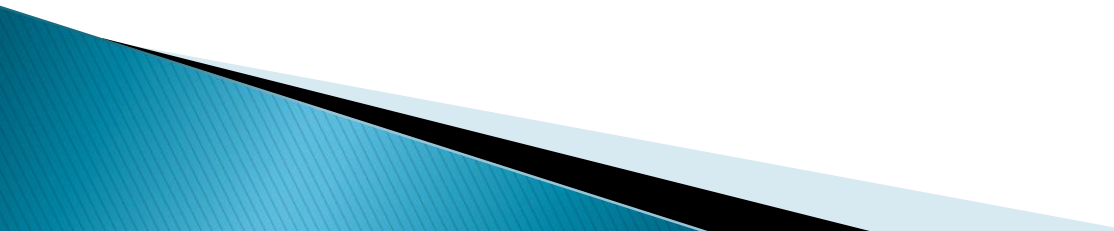
The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

The **recycling process** of the construction waste on site, done by a crusher machine is formed by four main steps:

- Waste selection at the construction site;
- Inserting the waste into the crusher machine;
- Crushing the waste in the crusher machine;
- Delivering the crushed waste (base material) by trucks.

This **recycling process** is part of the green construction demands of Maracanã reconstruction, as well as element for the sustainable safety of the site construction.



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales

Weighting of output variability: recycling process activity.

Vectors of priorities (weight of variability – output)					
Functions/criteria	Sequence (S)	Force, distance and direction (F)	Timing and duration (T)	Wrong object (O)	Consistency ratio
Initial checklist	0.431	0.038	0.1	0.431	0.094
Operation without load	0.218	0.043	0.65	0.089	0.082
Operation under load	0.044	0.142	0.142	0.672	0.09
Control of the finished product	0.097	0.044	0.227	0.632	0.077
Material selection	0.054	0.054	0.306	0.586	0.034
Material delivery	0.062	0.438	0.438	0.062	0
Receive material	0.058	0.672	0.212	0.058	0.091
Levelling control	0.053	0.053	0.269	0.625	0.09

The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales

Weightings of upstream-downstream coupling

Functions/criteria	Vectors of priorities					Consistency ratio
	Upstream-downstream coupling weights					
	Input	Time	Resources	Preconditions	Control	
Operation with no load	0.051	0.051	0.051	0.57	0.277	0.053
Operation under load	0.428	0.048	0.048	0.048	0.428	0
Control of the product (finished)	0.634	0.111	0.111	0.057	0.087	0.036
Material delivery	0.639	0.061	0.061	0.181	0.058	0.036
Receive material	0.586	0.05	0.05	0.264	0.05	0.086
Levelling control	0.03	0.162	0.149	0.51	0.149	0.046

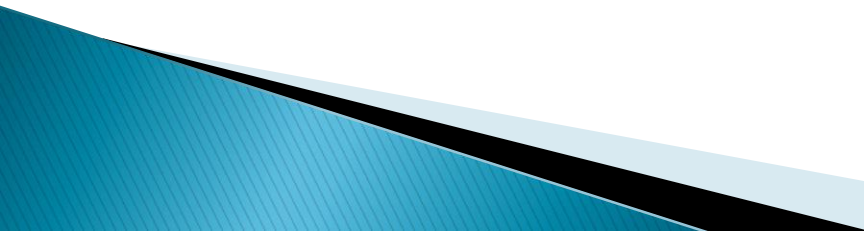
The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

The determination of possible functional resonances, the sources for variability that may produce undesired outcomes, is based on the potential couplings among functions.

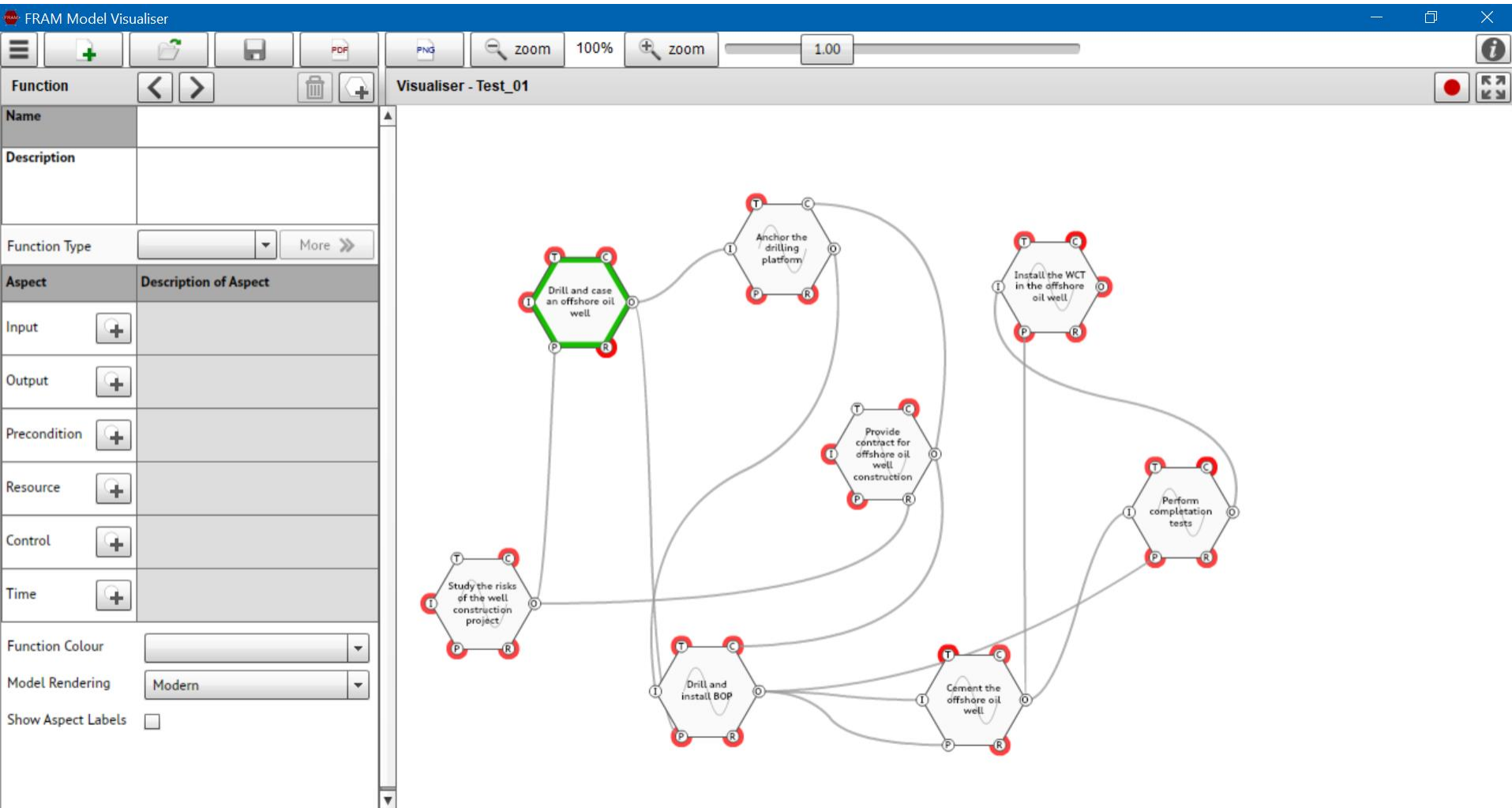
Using AHP, vectors of priorities related with output variability linked with the vectors of priorities of the upstream-downstream coupling show the **priority functional resonance** links.

The connections where there are more variation possibilities in the couplings is due to **high values in the function output and in one of the downstream function entrances**.



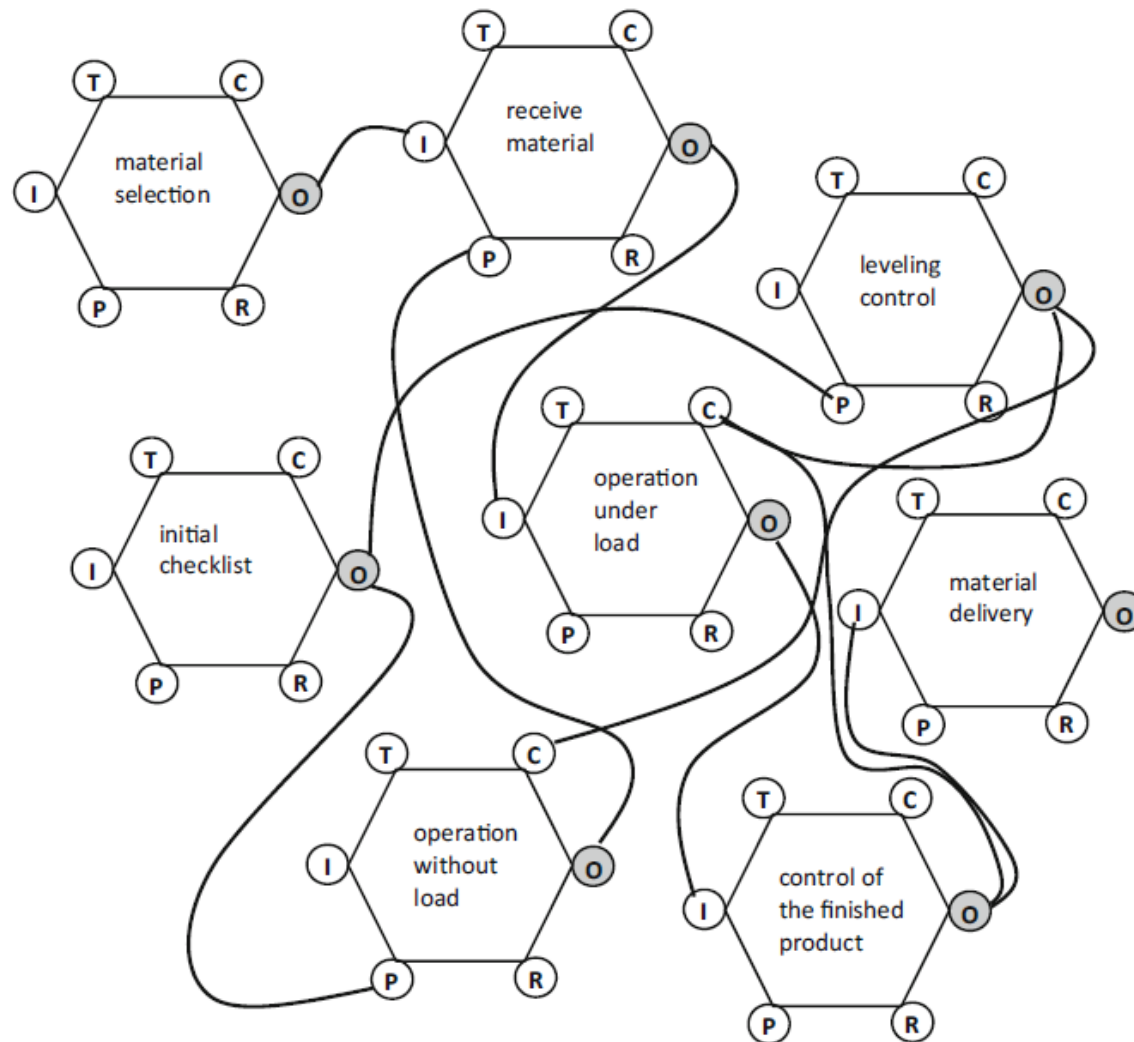
The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales



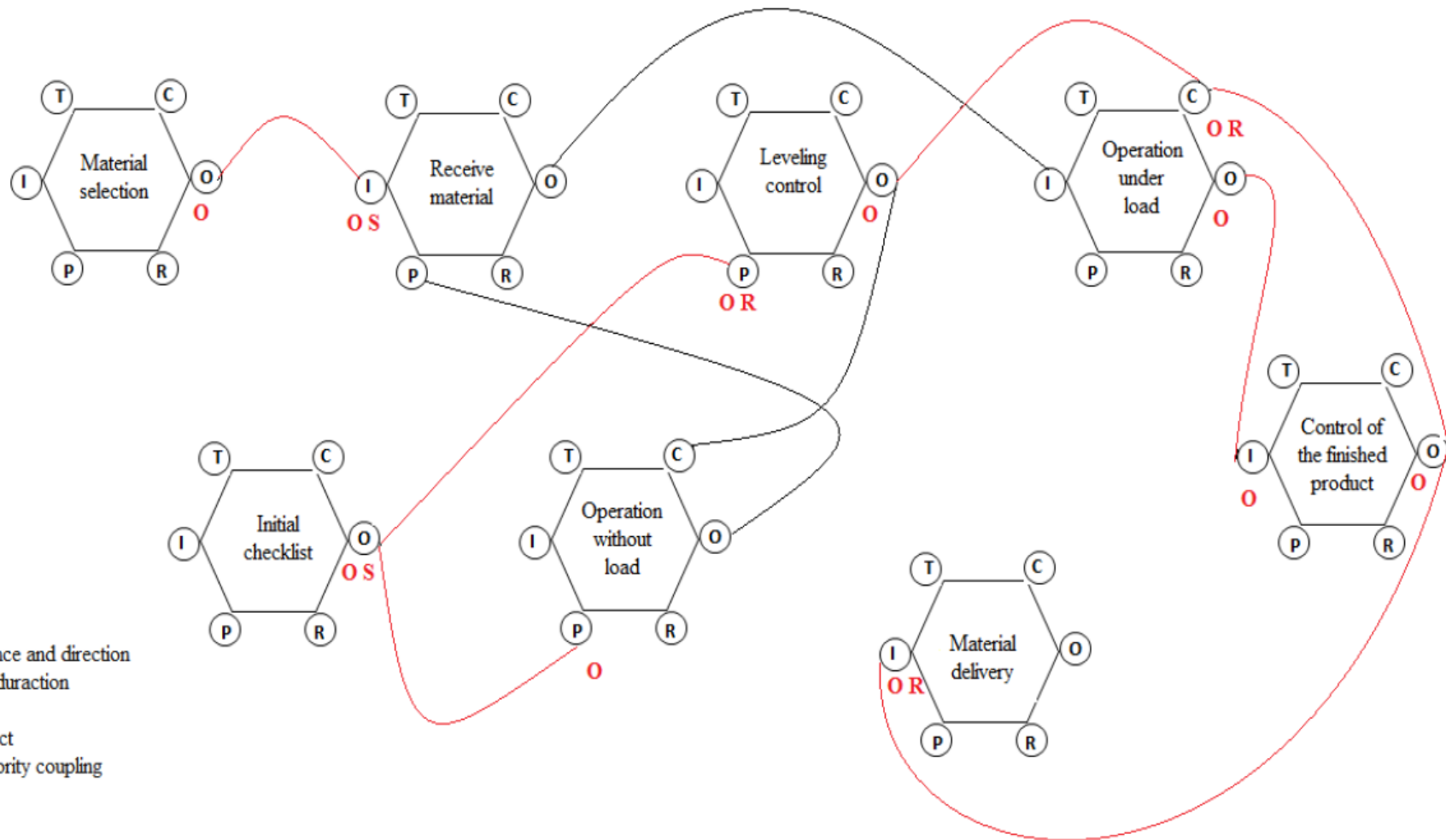
The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University, Wales



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

Cardiff University , Wales

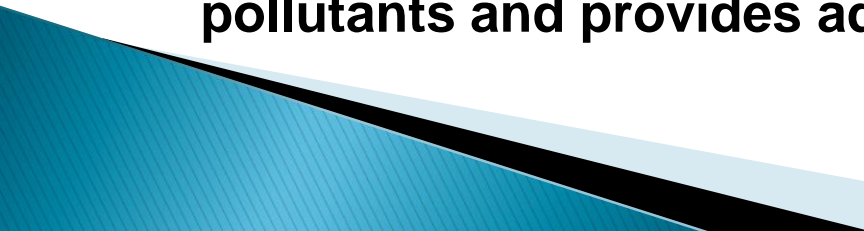
Based on this study, the effectiveness of the system demands the correct levelling of the equipment involved in the operations.

Levelling control has high variability in preconditions (timing and wrong object), which reflects in its output.

Variability in the level control output causes difficulties for the control of the function 'Operation under load'.

This means that if levelling **shows high variation during operations**, loading and unloading is going to happen in highly variable conditions, leading to a loss of control.

It is also important to notice that adequate levelling of the equipment **reduces consumption of energy, the level of noise, the spread of pollutants and provides adequate productivity of the process.**



The 12th FRAMily meeting/workshop, June 11th - 13th 2018

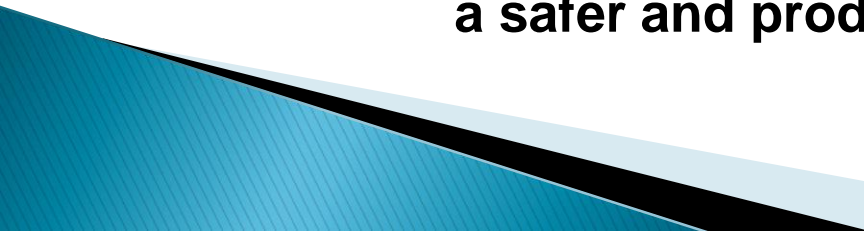
Cardiff University , Wales

As a **direct result** of the combined application of **FRAM** and **AHP** on the Maracanã reconstruction, the levelling of the crusher machine was **analyzed and fixed** for an adequate standard.

Once this action was done in advance, as **Resilience Engineering** postulates, since the levelling correction till the end of the construction site, no accidents happened in this area.

Furthermore, the operation had increased its performance and the dust in the air was highly reduced, **ensuring the requirements for green construction and sustainable safety**.

FRAM not only helped to understand the routine performance of the functions in Maracanã reconstruction, but also **really contributed to a safer and productive work environment**.





***Serch hynny, cymhleth yw
system dechnolegol, ni fydd
mor gymhleth â'r dynol.***

Josué Eduardo Maia França

Diolch!

***Among the various complex
systems in the World, the
Humans are the most
complex system of all.***

Josué Eduardo Maia França

Thanks!

