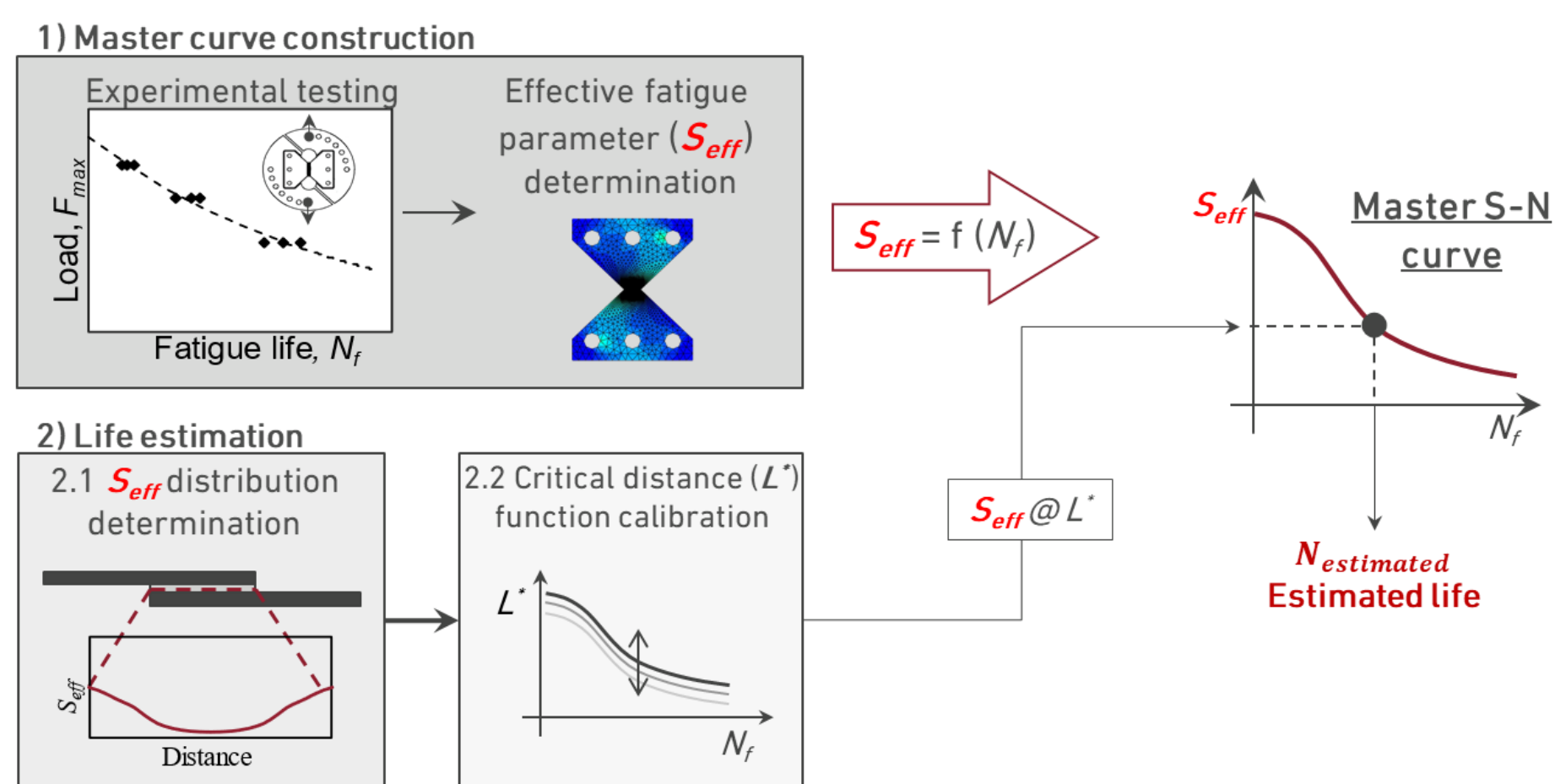# INEGI driving science & innovation

LUCAS GROUP

Fatigue of adhesive joints: a well-studied yet persistently challenging phenomenon

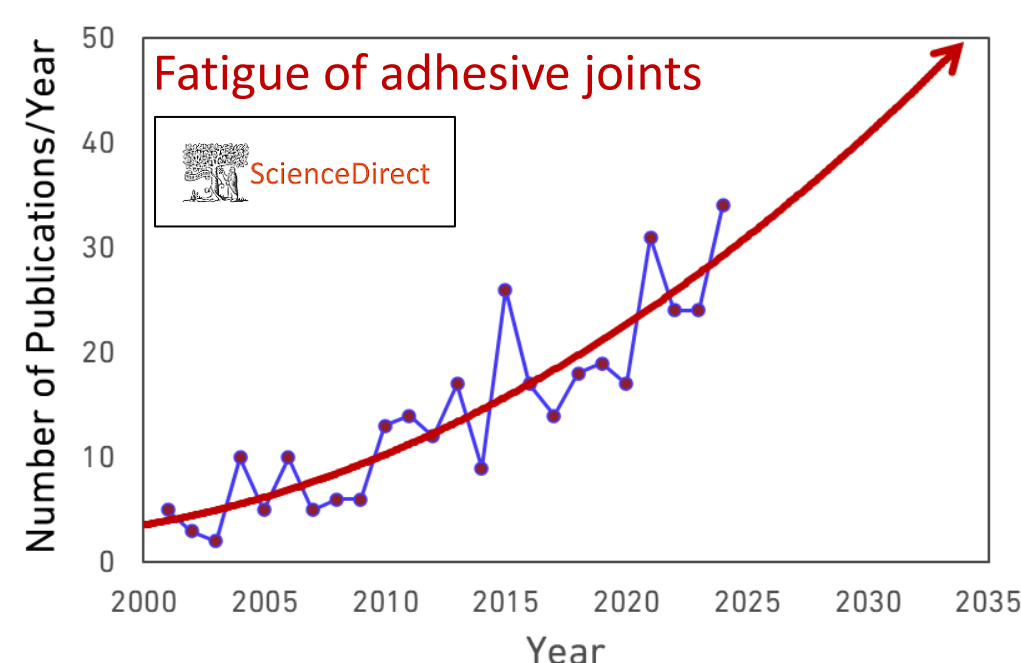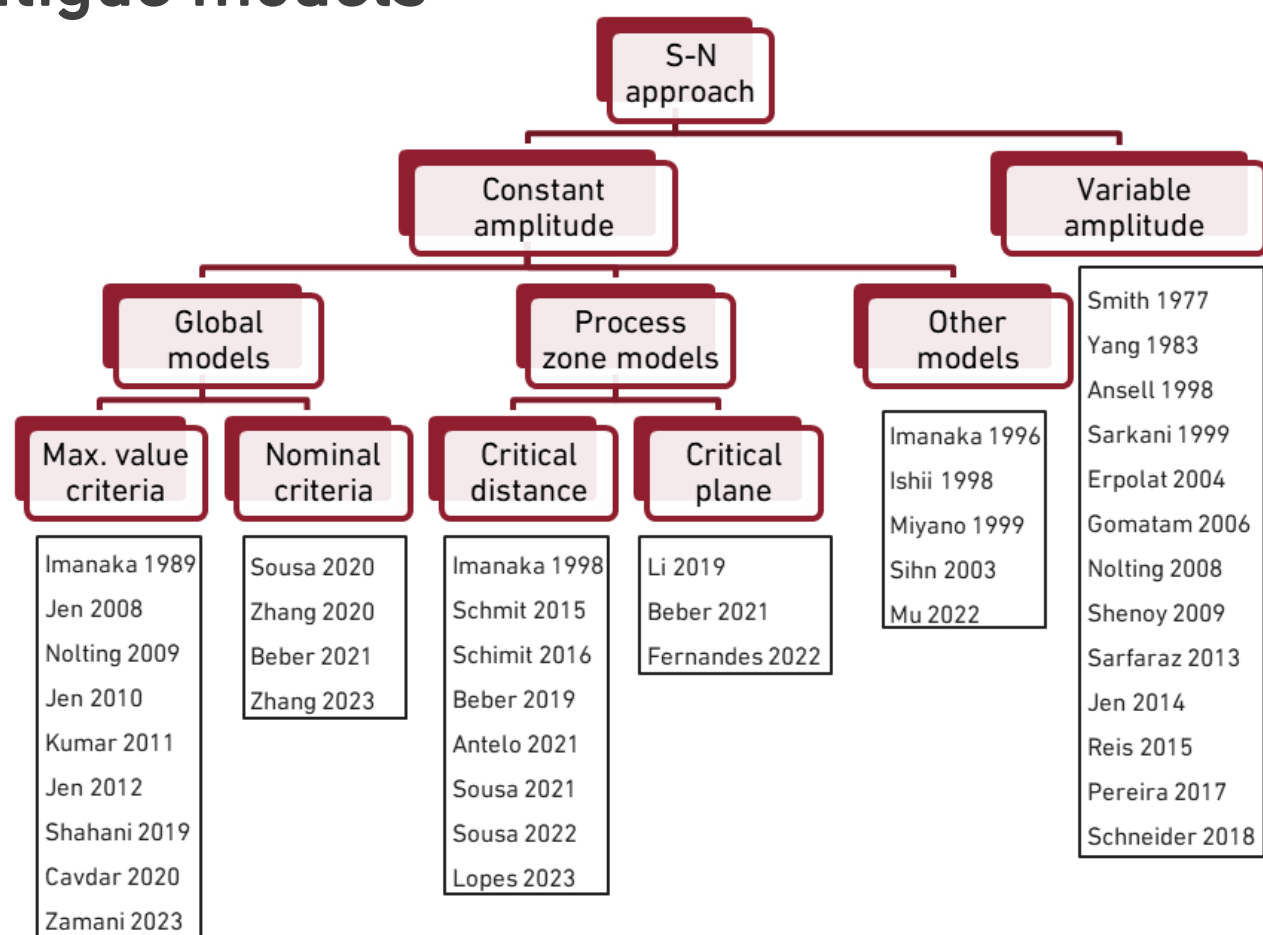A Akhavan-Safar (INEGI, Portugal) | RJC Carbas | EAS Marques | Lucas F.M. da Silva

1. Introduction

Adhesive bonding offers major advantages across industries, but its long-term durability—especially under fatigue and environmental aging—remains a critical challenge. Inaccurate fatigue life prediction has limited the use of adhesive joints as the sole joining method in primary structures. Despite extensive research, current software lacks fatigue models tailored to adhesive joints, leaving engineers without practical tools. To address this gap, our research group is developing the first dedicated software for fatigue life prediction of adhesive joints, in collaboration with both manufacturers and end-users.
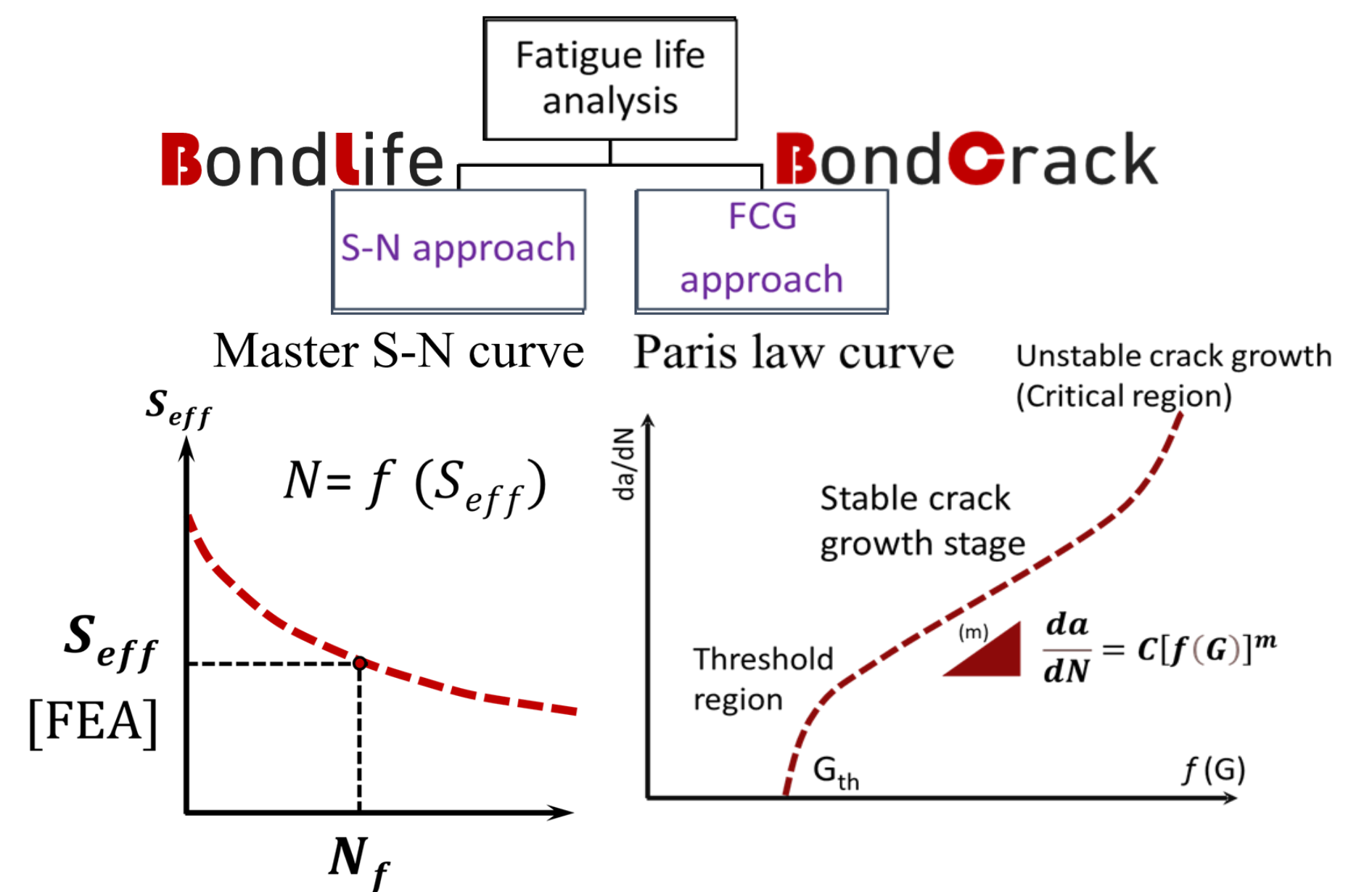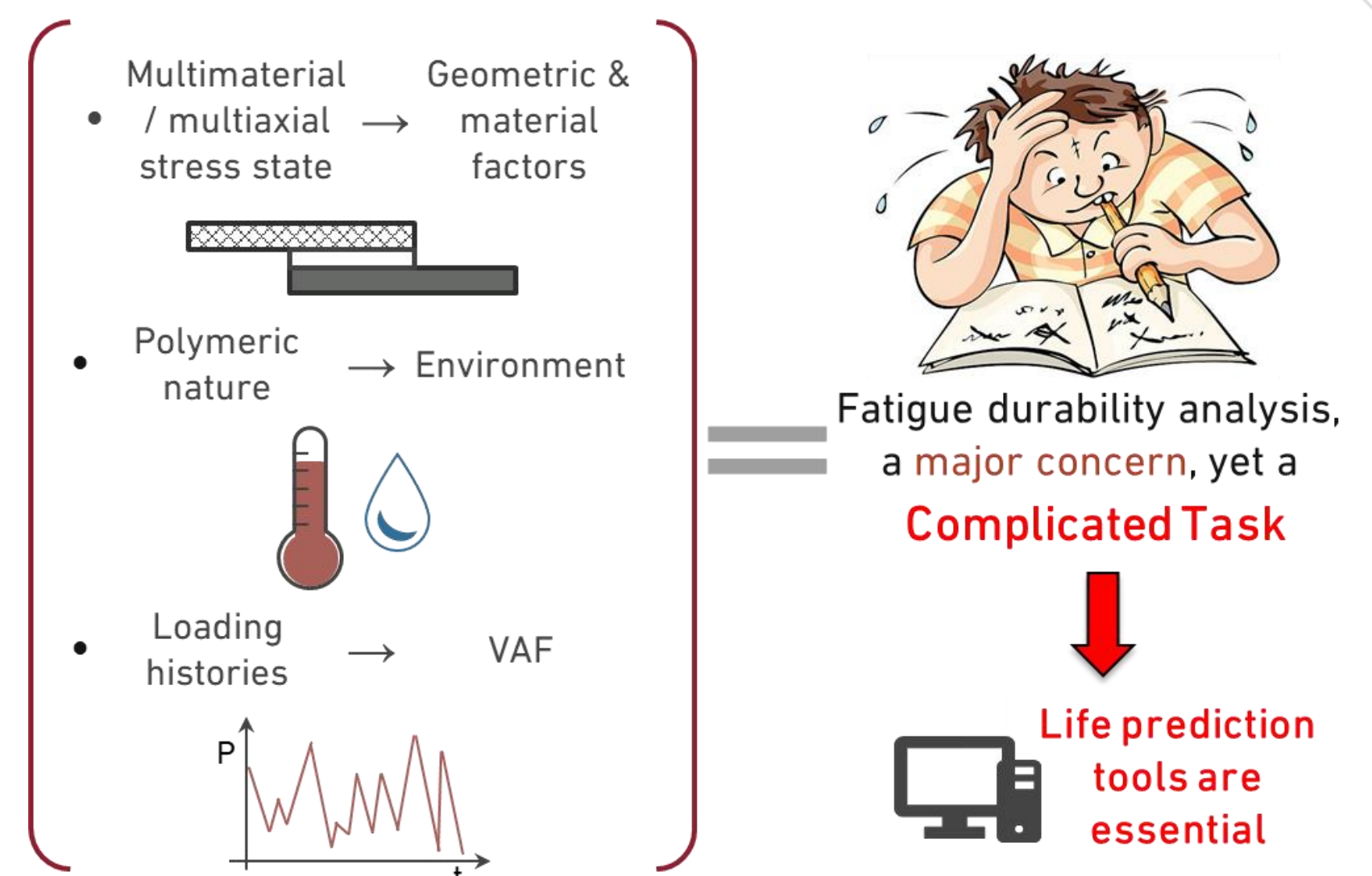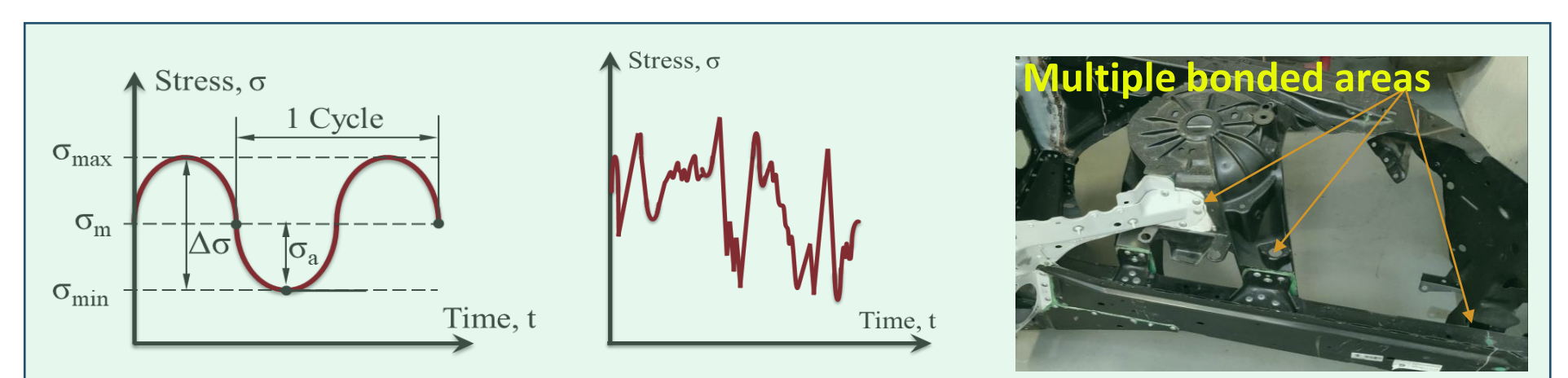
2. Method

1) Master curve construction
Experimental testing — Effective fatigue parameter (S_{eff}) determination
$S_{eff} = f(N_f)$
S_{eff}
Master S-N curve
Load, F_{max} — Fatigue life, N_f
N_f
$S_{eff} @ L^*$
$N_{estimated}$ Estimated life

2) Life estimation
2.1 S_{eff} distribution determination
2.2 Critical distance (L^*) function calibration
S_{eff} — Distance
L^* — N_f

3. Fatigue models

S-N approach
— Constant amplitude
— Variable amplitude

Constant amplitude:
— Global models
— Process zone models
— Other models

Global models:
— Max. value criteria: Imanaka 1989, Jen 2008, Nolting 2009, Jen 2010, Kumar 2011, Jen 2012, Shahani 2019, Cavdar 2020, Zamani 2023
— Nominal criteria: Sousa 2020, Zhang 2020, Beber 2021, Zhang 2023

Process zone models:
— Critical distance: Imanaka 1998, Schmit 2015, Schmit 2016, Beber 2019, Antelo 2021, Sousa 2021, Sousa 2022, Lopes 2023
— Critical plane: Li 2019, Beber 2021, Fernandes 2022

Other models: Imanaka 1996, Ishii 1998, Miyano 1999, Sihn 2003, Mu 2022

Variable amplitude: Smith 1977, Yang 1983, Ansell 1998, Sarkani 1999, Erpolat 2004, Gomatam 2006, Nolting 2008, Shenoy 2009, Sarfaraz 2013, Jen 2014, Reis 2015, Pereira 2017, Schneider 2018

Fatigue of adhesive joints
ScienceDirect
Number of Publications/Year vs Year (2000–2035)

MSC Software | FEMFAT software | Ansys NCODE DESIGNLIFE | fe-safe

4. Novel fatigue life prediction tools

- Multimaterial / multiaxial stress state → Geometric & material factors
- Polymeric nature → Environment
- Loading histories → VAF
P vs t

Fatigue durability analysis, a *major concern*, yet a **Complicated Task**

Life prediction tools are essential

Fatigue life analysis

BondLife — S-N approach — Master S-N curve
BondCrack — FCG approach — Paris law curve

s_{eff}
$N = f(S_{eff})$
S_{eff} [FEA]
N_f

da/dN
Unstable crack growth (Critical region)
Stable crack growth stage
Threshold region
$\frac{da}{dN} = C[f(G)]^m$
G_{th}
$f(G)$

BondLife
An Innovative Software Dedicated to the S-N Fatigue Life Prediction of Adhesively Bonded Joints

BondCrack
A Numerical Tool for Fatigue Crack Growth (FCG) Analysis of Adhesively Bonded Joints Using Cohesive Zone Modelling

5. Some features

Stress, σ — 1 Cycle — σ_{max}, σ_m, σ_{min}, $\Delta\sigma$, σ_a — Time, t

Stress, σ — Time, t

Multiple bonded areas

6. Conclusions

Adhesive bonding faces durability challenges, particularly in fatigue life prediction. To address this, two novel tools—**BondLife** for S-N fatigue analysis and **BondCrack** for fatigue crack growth via cohesive zone modelling—are being developed collaboratively.