Newcastle University

EPSRC National Centre for Energy Systems Integration Webinars

AI-driven Engineering Design for Energy System

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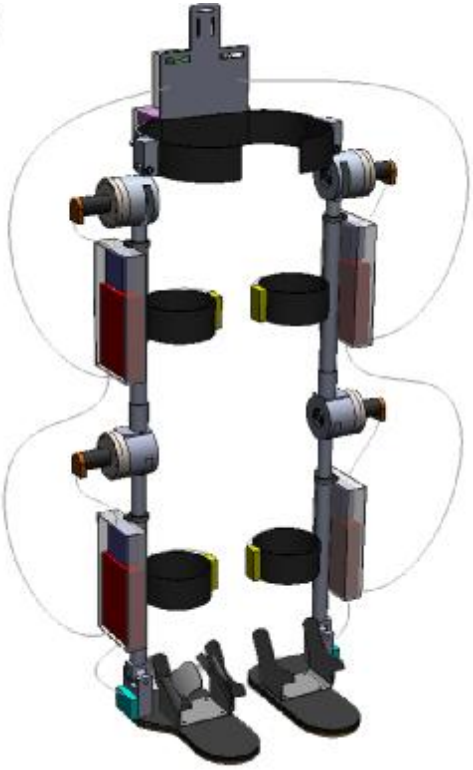
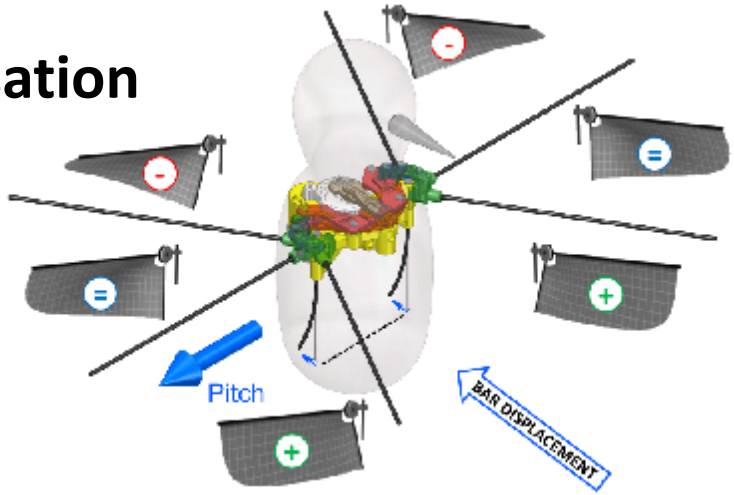
Research Interests

- **Artificial Intelligence** and Cross-disciplinary Applications
- **Industry 4.0**, Digital Twin and Digital Manufacture
- **Robotics** and Autonomous Systems
- **Data** Analytics



Contents

- Computational Intelligence Aided Design (CIAD)
- Electricity Consumption Modelling
- Firefly Algorithm
- Trend Indices for Evolutionary Optimisation
- Simulation and Results
- Conclusions and Future Works



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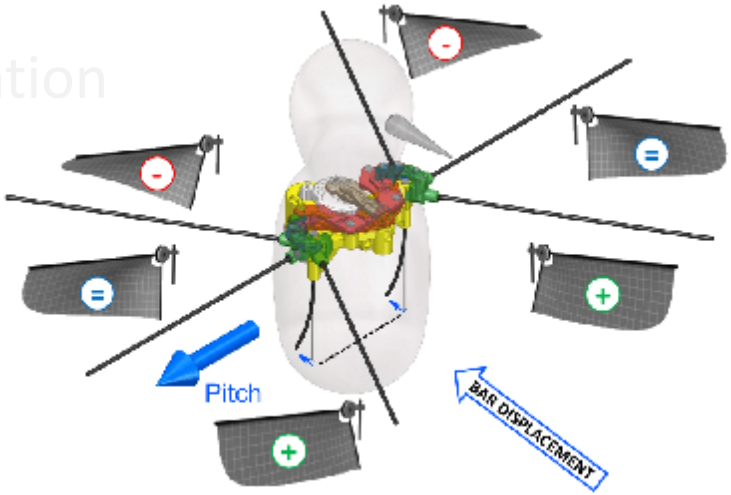
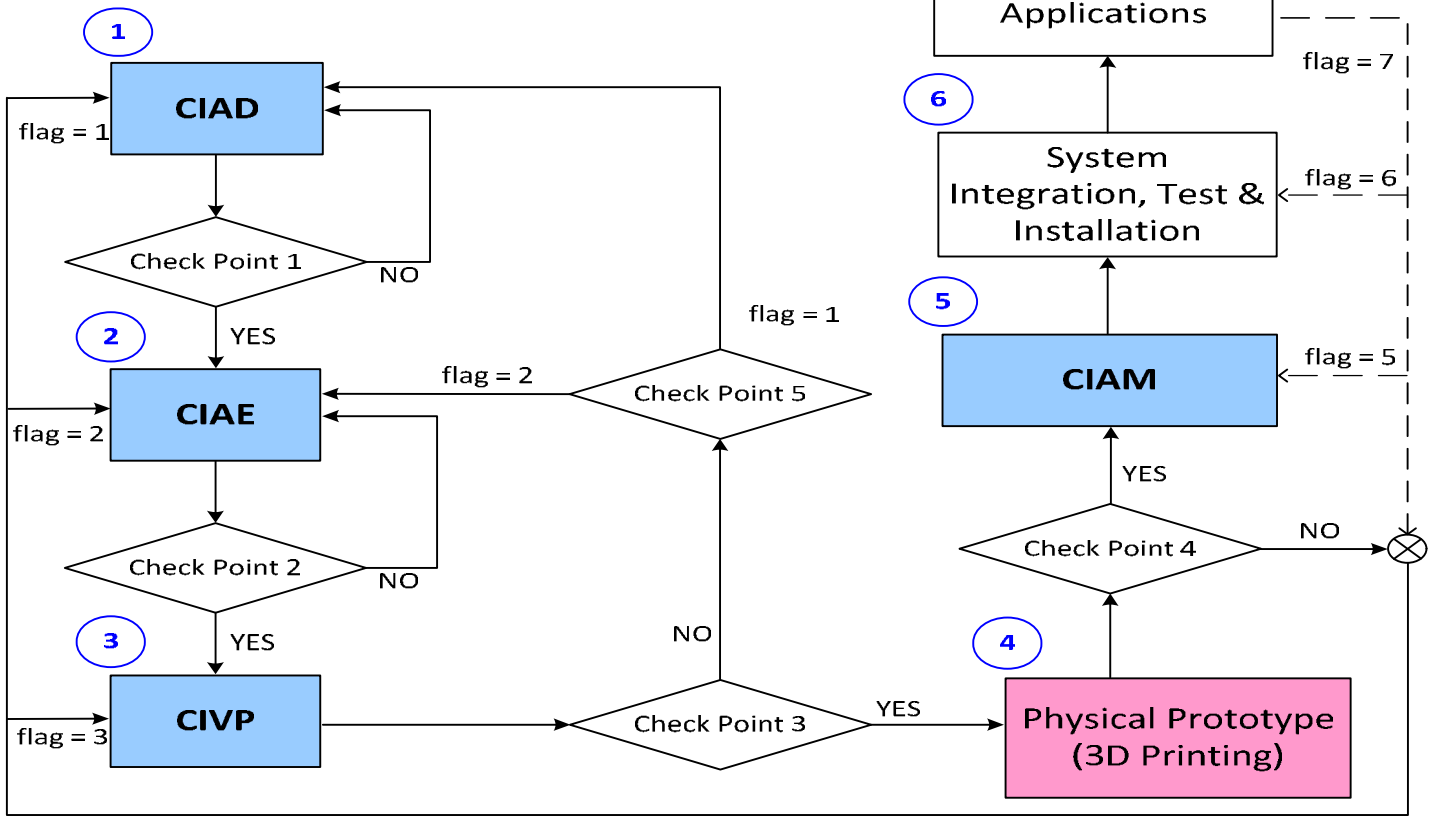


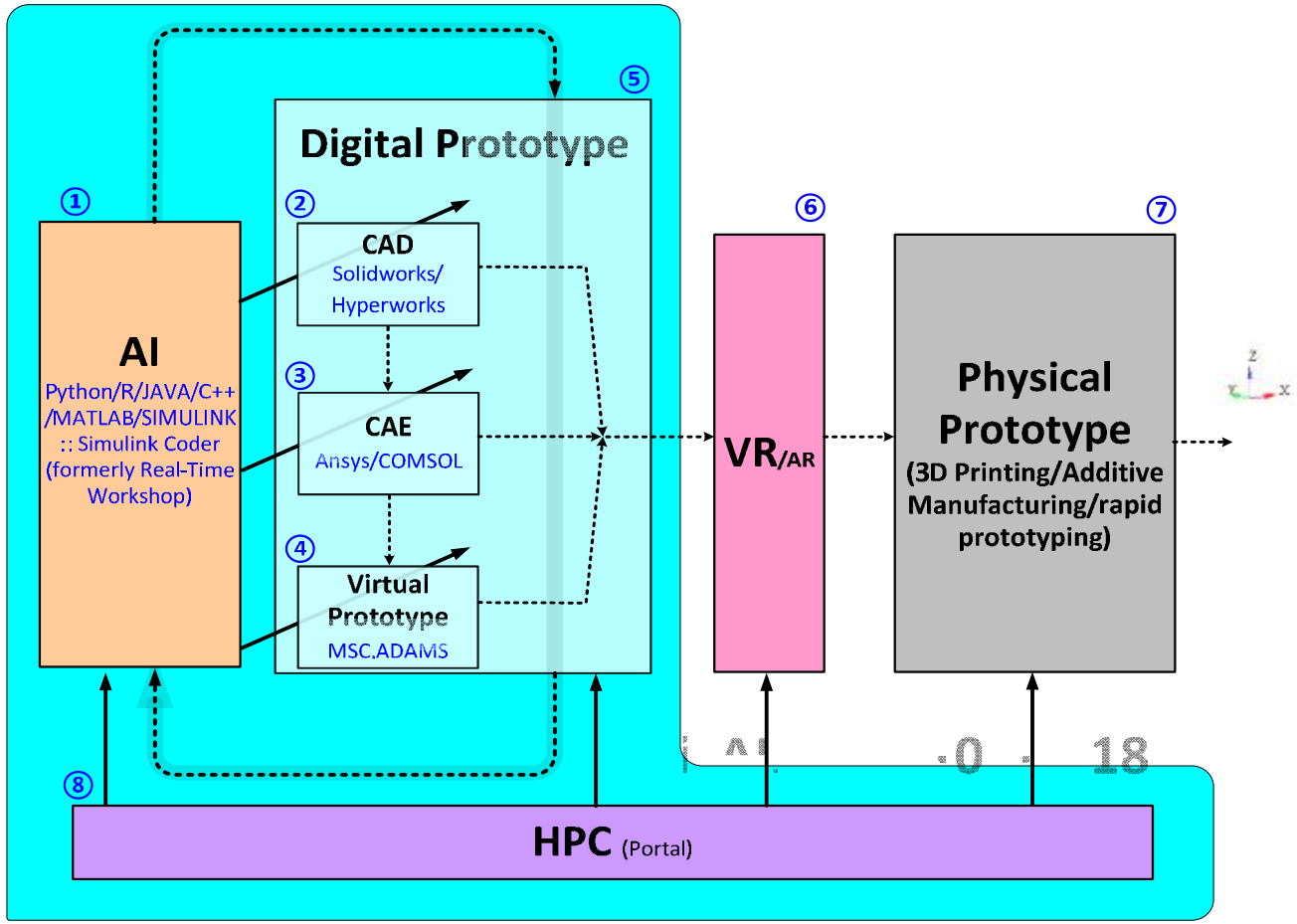
Computational Intelligence Aided Design (CIAD)

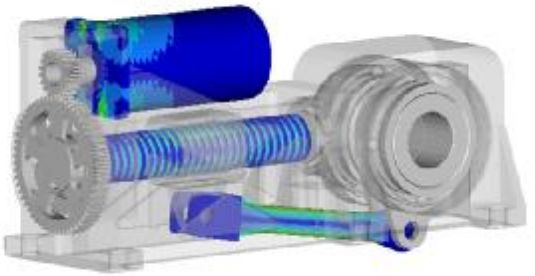
Use Case to ISO/IEC JTC 1/SC 42 Artificial intelligence Sub committee

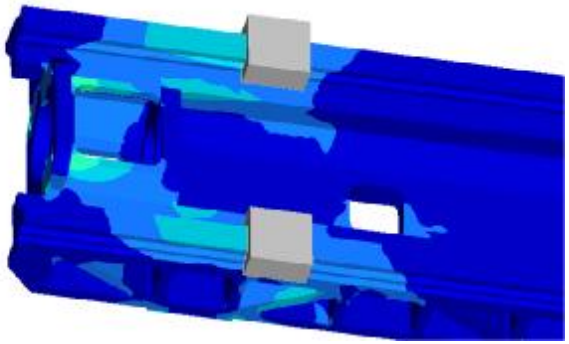
CIAD = Computational Intelligence Aided Design
CIAE = Computational Intelligence Aided Engineering
CIVP = Computational Intelligence Aided Virtual Prototype
CIAM = Computational Intelligence Aided Manufacturing



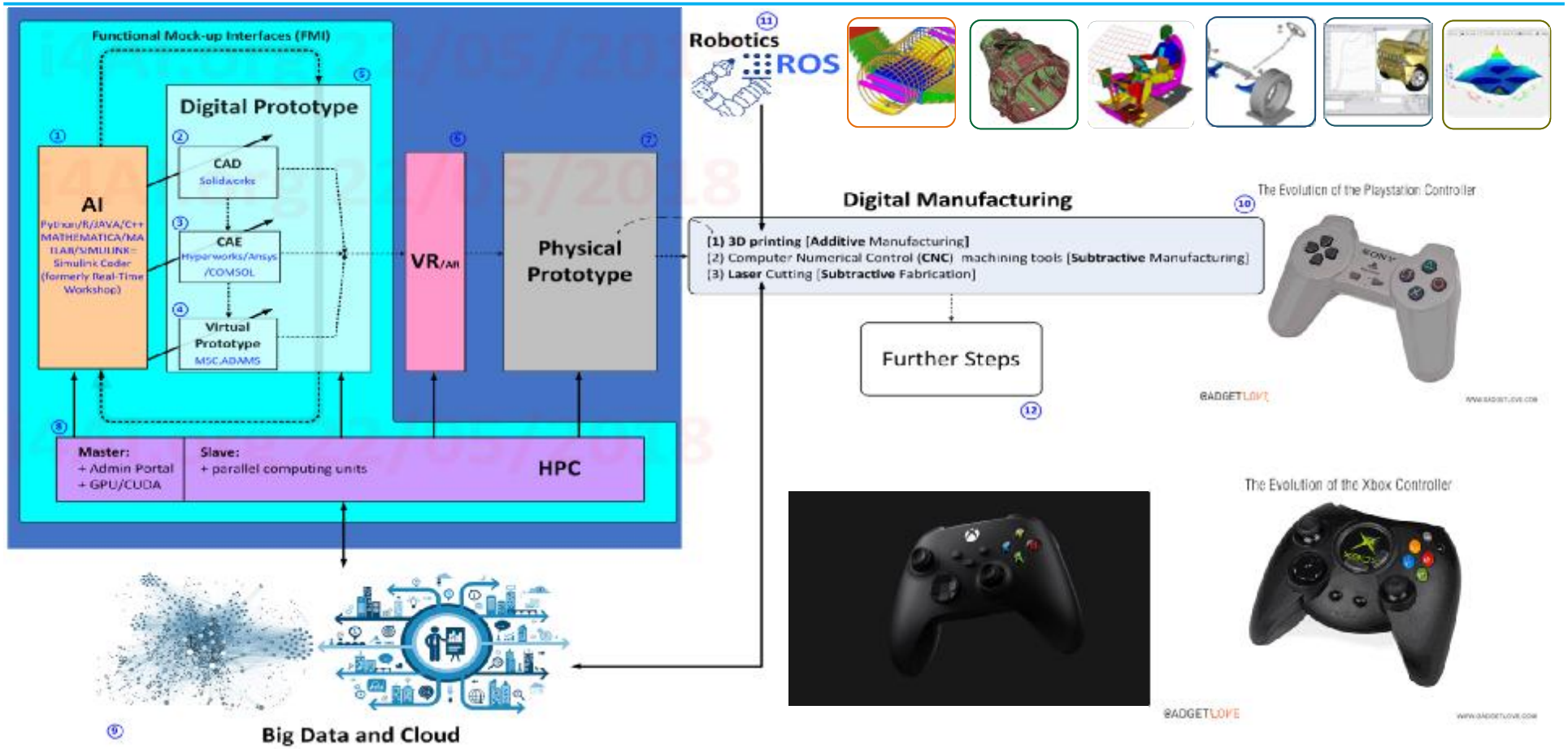
CIAD **Implementation** Supported by HPC

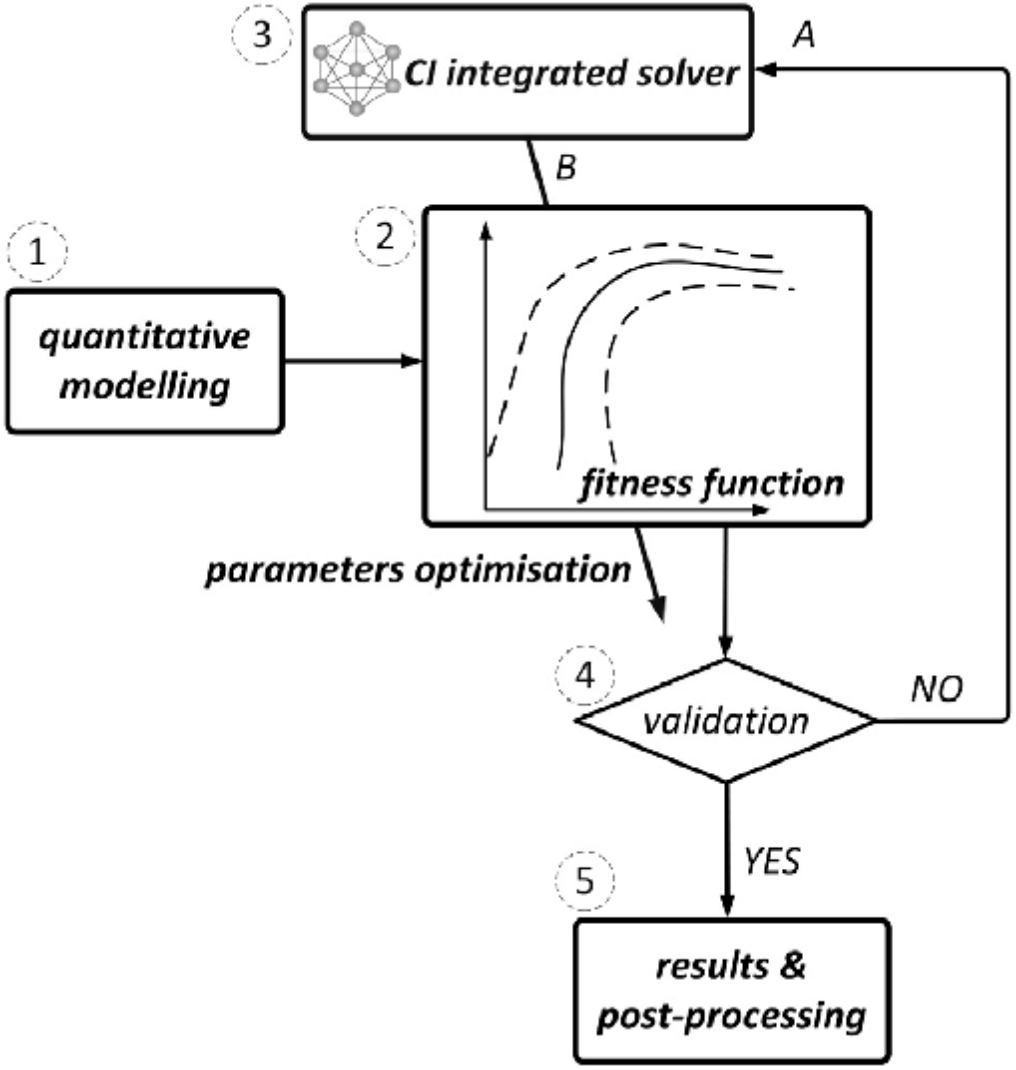






CIAD for Digital Manufacturing





CIAD Framework for Energy Modelling

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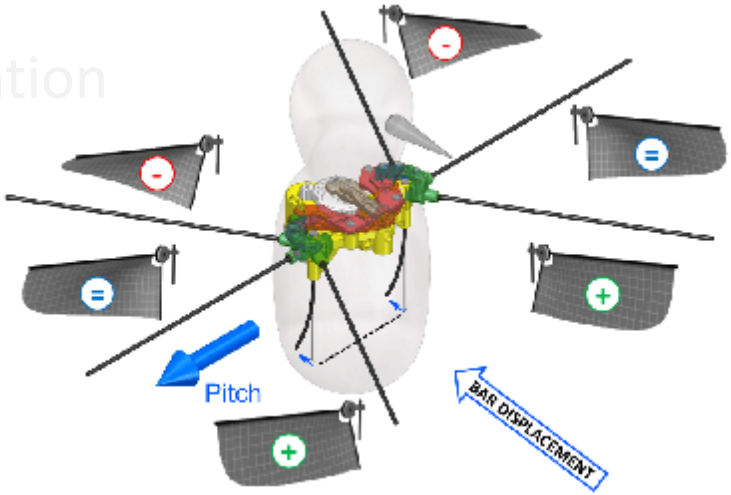


Electricity Consumption Modelling[1]

$$\widehat{EC}(C_0, \Theta, \Omega) = C_0 + \theta_1 X_1^{\omega_1} + \theta_2 X_2^{\omega_2} + \theta_3 X_3^{\omega_3} + \theta_4 X_4^{\omega_4} + \theta_5 X_5^{\omega_5}$$

- $\widehat{EC}$ is the estimation of annual national electricity consumption, GW h/year;
- C_0 is a design variable of data shifting;
- $\Theta = [\theta_1, \theta_2, \ldots, \theta_i, \ldots, \theta_{n_1}]$ is a design variable of the coefficient vector of X_i, n_1 is the number of design variable;
- $\Omega = [\omega_1, \omega_2, \ldots, \omega_i, \ldots, \omega_{n_1}]$ is a design variable of the exponent vector of X_i;
- $X_i = [X_1, X_2, X_3, X_4, X_5]$ is the vector of the impact factors, in which, X_1 is the GDP; X_2 is the electricity price; X_3 is the efficiency, which is the ratio of national output over electricity consumption; X_4 is the economic structure, which is the ratio of residential consumption over industrial production; X_5 is the CO_2 emission in billion of metric tons.

Definition of fitness function

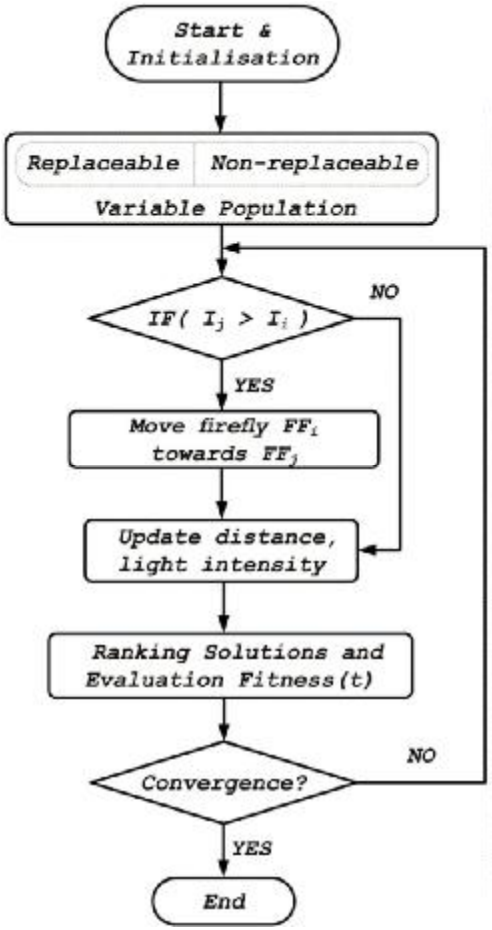
fitness = $Maximise : \left\{ mmAP\left(-RMS\left(\widehat{EC}(C_0, \Theta, \Omega) - EC_0 \right) \right) \right\}$

in which,

- **RMS - root mean square**
- **mmAP** in section ' Trend indices'

Contents

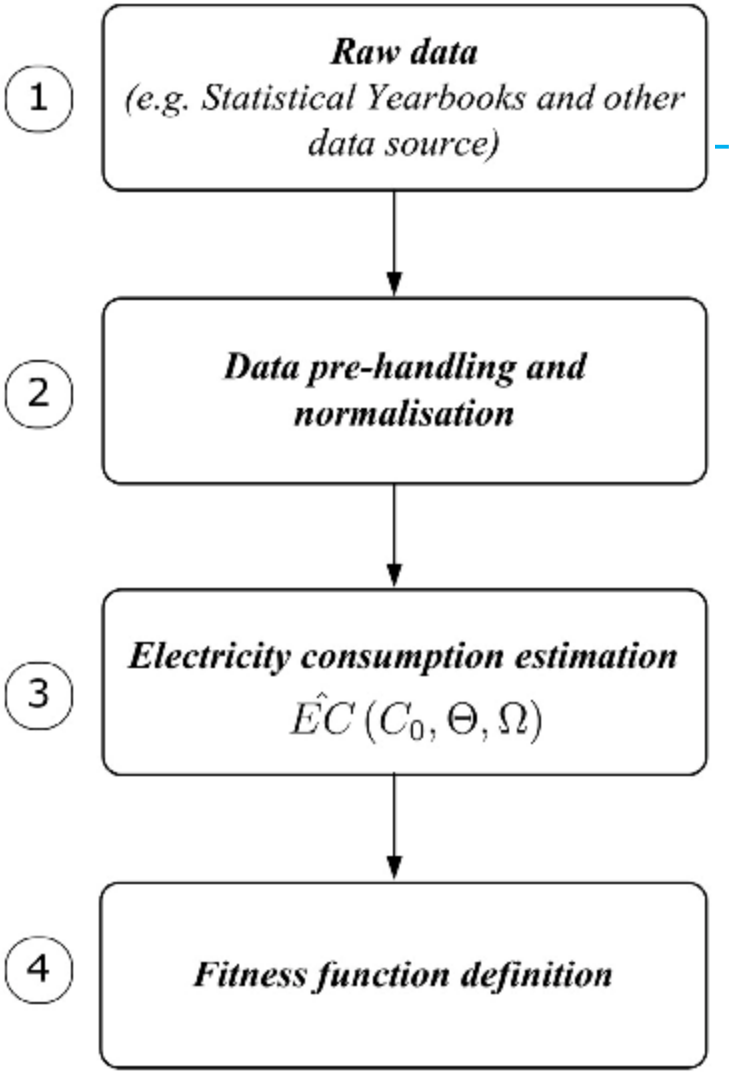
Firefly Algorithm[2]




```
Begin (1)

  t = 0 ;
  Initialise all parameters:
   x_i with variable population P, fitness(x_0),
   Light Intensity I_i, Initial Distances Di, etc.

    While ( Not termination-condition) do
      Begin (2)
         t = t + 1;
        FOR i = 1: Population
           FOR j = 1: Population
              IF( I_j > I_i)
                Move firefly i towards firefly j;
              ENDIF
              update distance;
              light intensity;
              attractiveness
           ENDj
         ENDi
      rank all fireflies;
      evaluation fitness(x);
      best solutions;

      End (2)

End (1)
```

Firefly Algorithm

SwarmFireFly - The Firefly Swarm Algorithm (FFSA).
https://www.mathworks.com/matlabcentral/fileexchange/38931-swarmfirefly-the-firefly-swarm-algorithm-ffsa



Contents

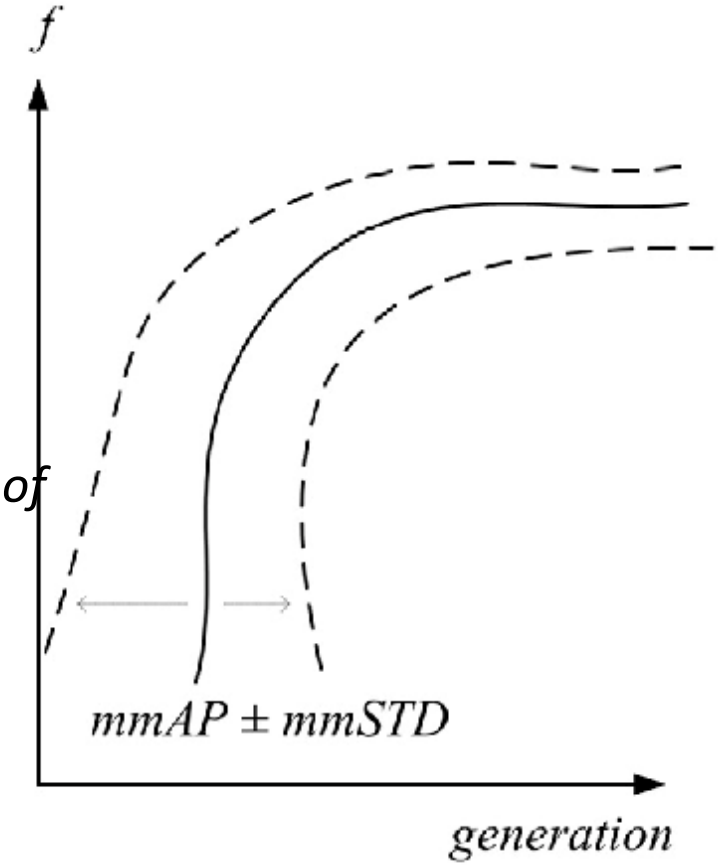
Trend Indices for Evolutionary Optimisation

- *The index of **mmAP** is a **moving average** score of the **mean value** of vector fj*

$$mmAP(f_j) = \frac{1}{p}\sum_{i=1}^{p}\left(\frac{1}{i}\sum_{j=1}^{i} MEAN(f_j)\right)$$

- *The index of **mmSTD** is a **moving average** score of the **STD** value of vector fj*

$$mmSTD(f_j) = \frac{1}{p}\sum_{i=1}^{p}\left(\frac{1}{i}\sum_{j=1}^{i} STD(f_j)\right)$$



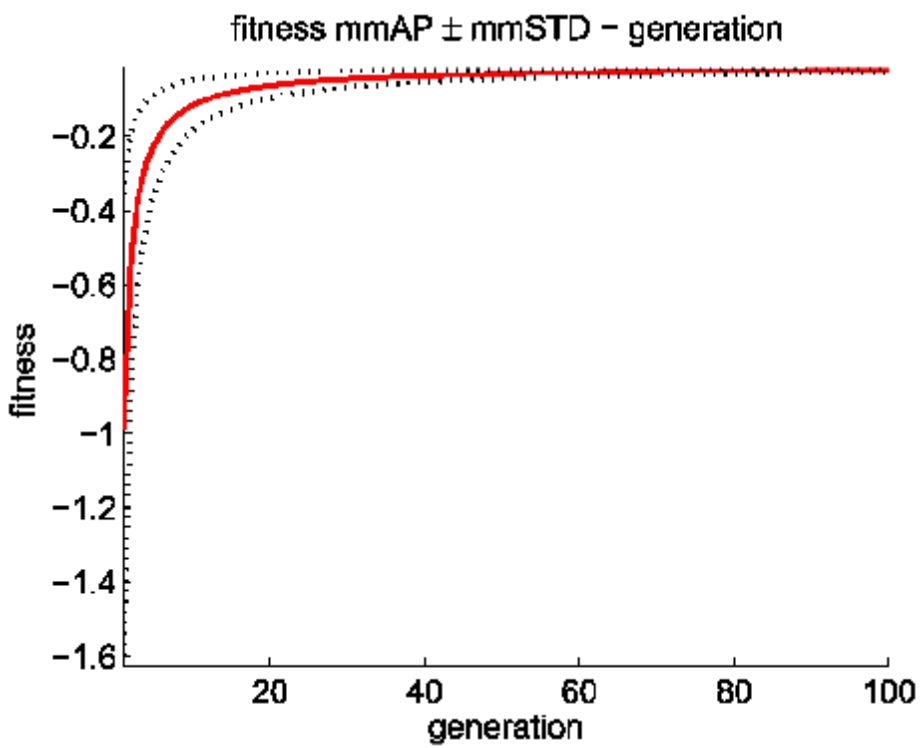
Contents

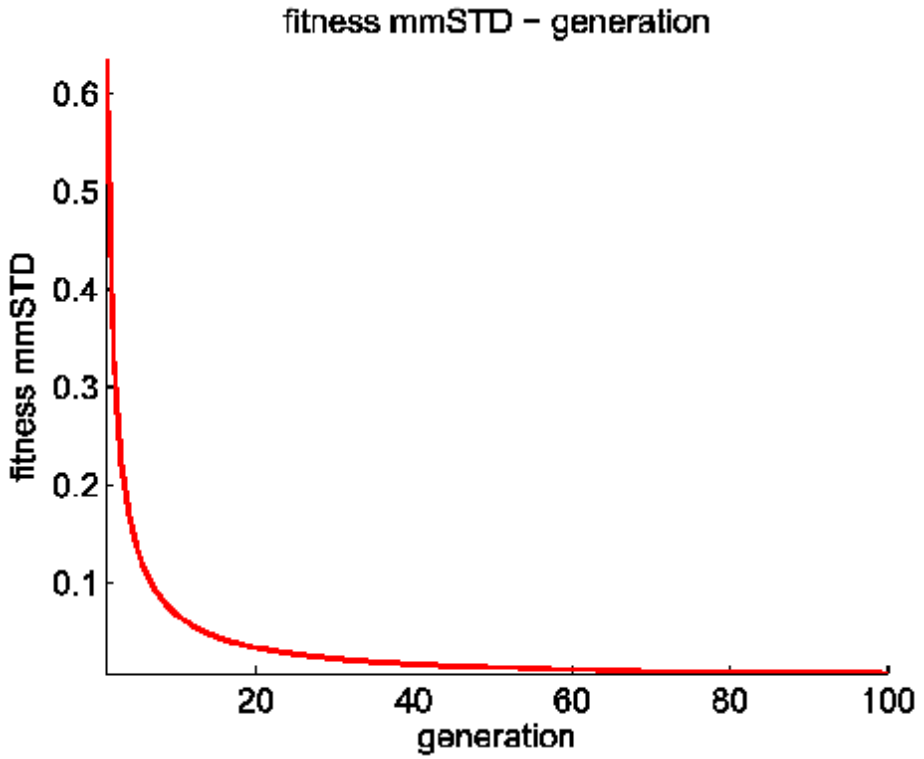
Simulation and Results

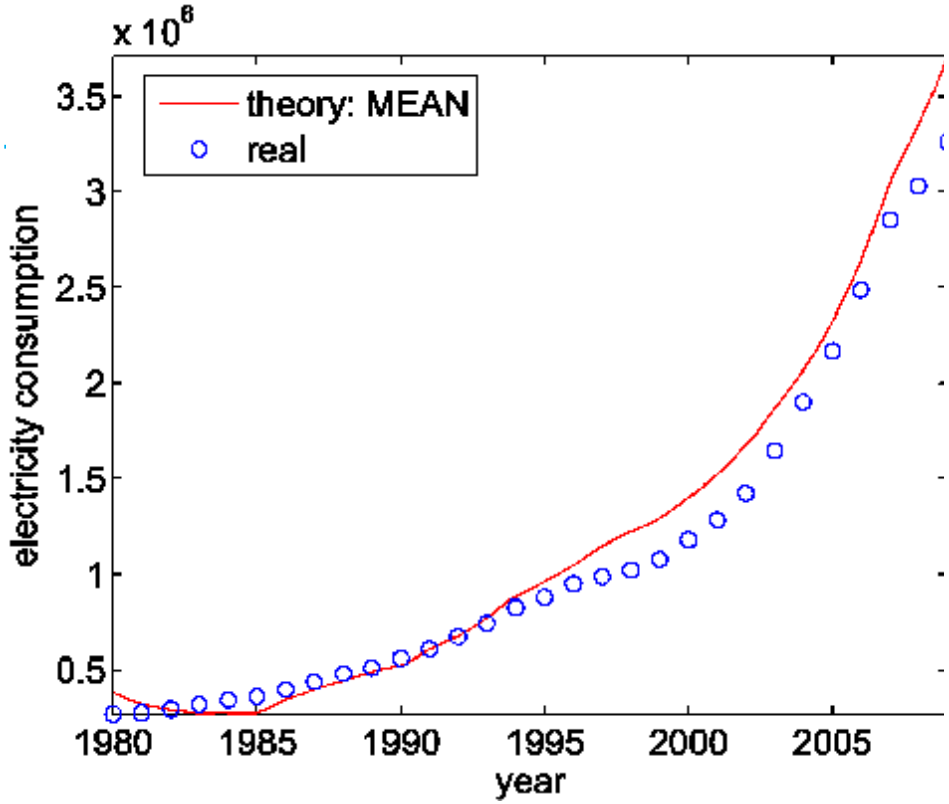
Initial parameters of the Swarmfirefly.

Max-Generations	100
Test number	100
Randomness	0.2
Randomness reduction	0.98
Population	50
Non-replaceable population	40
Replaceable population	10
Absorption coefficient	1
C_0	[−100, 100]
Θ	[−10, 10]
Ω	[0, 3]

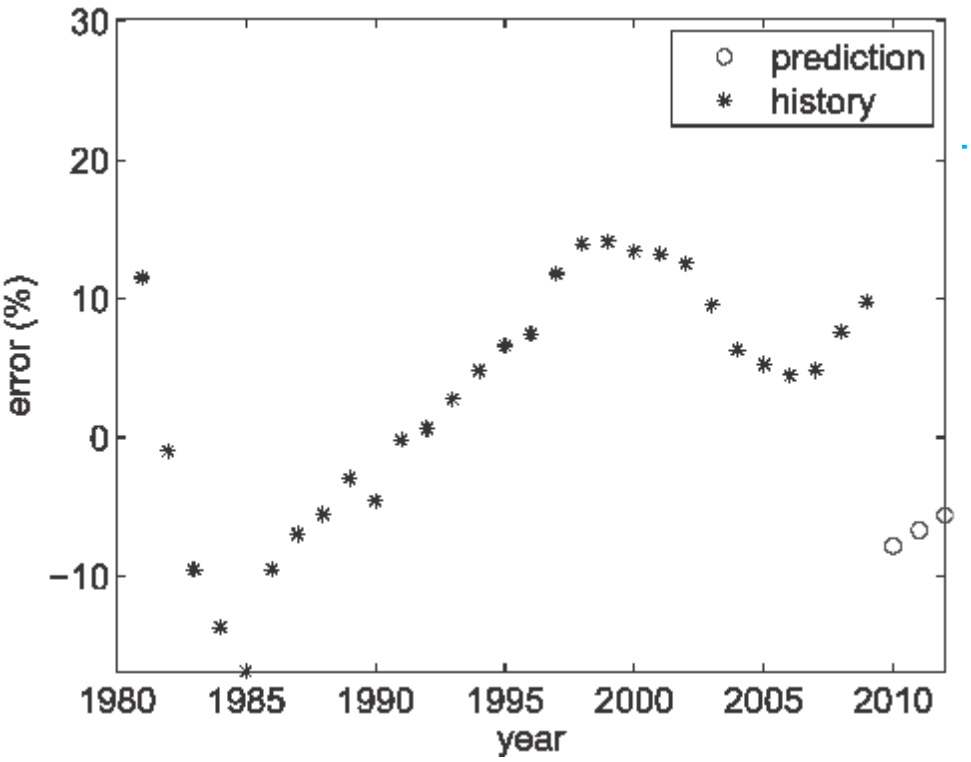
Simulation and Results







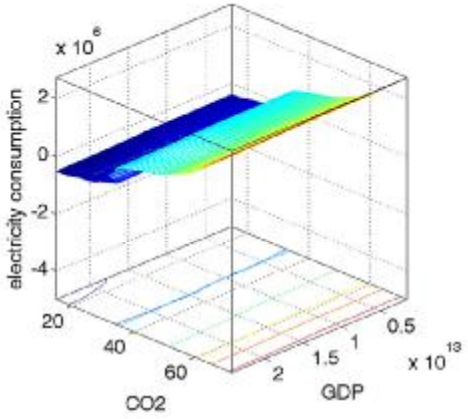
EC **approximation**,
years 1980 - 2009.



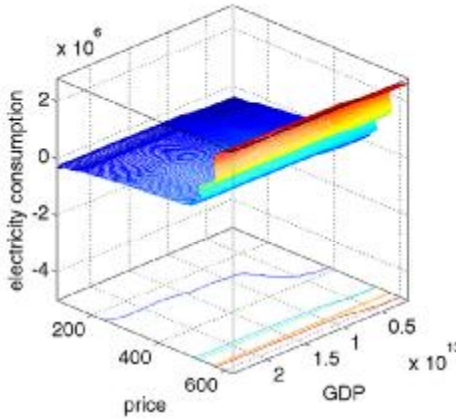
Error of EC approximation and
prediction for years 1980 - 2012.

Error of EC approximation and prediction.

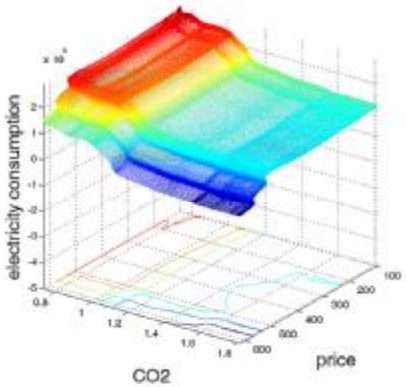
	Year	Error (%)
Approximation	1980–2009	5.9250 ± 13.9429
Prediction	2010	−7.7111 ± 5.45
Prediction	2011	−6.6781 ± 6.78
Prediction	2012	−5.6106 ± 5.49



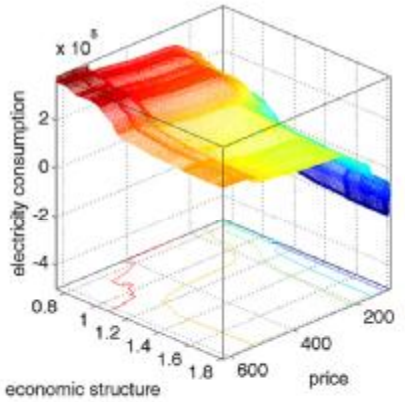
(a) EC vs. GDP, CO_2



(b) EC vs. GDP, price



(c) EC vs. price, CO_2



(d) EC vs. economic structure, price

Contents

Conclusions

1. The proposed prediction model for the national electricity consumption has a good **agreement** with the actual consumption data.

2. Under current social-economic structure, EC has a **direct impact** on the environment due to the heavy dependency on the conventional generation technology.

3. Energy consumption may **not** be able to directly boost the GDP growth under current social-economic **condition** and industry infrastructure, though GDP growth always implies a higher demand for **electricity**.

Future Works

- To develope **new** types of CI **algorithms**, such as swarm bat algorithm, swarm fish algorithm, and multi-objective genetic algorithm, to optimise energy consumption

- To **validate** the models based on sustainable and renewable energy data.

- To achieve long-term energy savings and carbon reduction, more **experimental** research is expected to establish social, economic, and environmental coupled behaviours.

Reference

[1] Quantitative modelling of electricity consumption using computational intelligence aided design. ***Journal of Cleaner Production***, 69, pp.143-152. (**IF= 6.395**)
https://www.sciencedirect.com/science/article/abs/pii/S0959652614000717

[2] Computational Intelligence Assisted Design - In Industrial Revolution 4.0
https://www.routledge.com/Computational-Intelligence-Assisted-Design-In-Industrial-Revolution-40/Chen-Li/p/book/9780367781040


Thanks and Questions