Recent Developments in CAD/analysis Integration

H. Lian\textsuperscript{a}, S.P.A. Bordas\textsuperscript{b,}\textsuperscript{*}, R. Sevilla\textsuperscript{b}, R.N. Simpson\textsuperscript{a}

\textsuperscript{a}Institute of Mechanics and Advanced Materials, School of Engineering, Cardiff University, Queen’s Building, The Parade, Cardiff CF24 3AA, Wales, UK
\textsuperscript{b}Civil and Computational Engineering Centre, College of Engineering, Swansea University, Faraday Building, Singleton Park, Swansea SA2 8PP, Wales, UK

Keywords: isogeometric analysis, review, mesh burden reduction, isogeometric boundary element methods, NURBS-enhanced FEM

Summary

It has been realised that integration of computer aided design (CAD) and numerical analysis is crucial for an efficient engineering design process. Many methods have been proposed in this area from a variety of perspectives, such as B-spline subdivision surfaces method, isogeometric analysis (IGA), NURBS-enhanced FEM and parametric-based implicit boundary definitions. This class of methods share the common features of employing the CAD data in analysis and possess the following main advantages:

\begin{itemize}
\item Difficulties in generating a geometry-conforming mesh can be alleviated greatly. Generating an analysis-suitable mesh is still difficult and time consuming, although mesh generators have developed quickly.
\item The geometry can be represented exactly. This property can enhance the analysis accuracy vastly, which is particularly obvious for shells, contact problems, fluid mechanics and several other applications.
\end{itemize}

In this paper, we place emphasis on IGA, whose key idea is to use the same basis functions to describe geometries and unknown fields. These basis functions include B-splines, NURBS (Non-Uniform Rational B-splines), T-splines, and PHT-splines. Their beneficial properties endow the IGA with several advantages in addition to the ones mentioned above:

\begin{itemize}
\item Flexible $hpk$ refinement schemes. Particularly, $k-$ refinement is noteworthy because it allows fewer degrees of freedom compared to $p-$ refinement and has no analogue in traditional FEM.
\end{itemize}

\textsuperscript{*}Corresponding author

\textit{Email address: stephane.bordas@alum.northwestern.edu} (S.P.A. Bordas)
• Easy construction of high order continuous fields for problems such as plates and shells, gradient elasticity, and phase fields.

• Easily to be incorporated into existing FEM codes, especially utilising Bézier extraction which leads to a familiar element assembly routine for IGA.

We review in this paper the basic theory of CAD design technology and the application and recent advances of isogeometric analysis. Furthermore, we compare IGA with other methods easing meshing difficulties, e.g. meshfree methods, implicit boundary methods, scaled boundary finite element methods etc. After comparing these methods, it is found that main limitations and future directions of IGA are

• An efficient quadrature rule for rational basis functions still needs further investigation.

• A general and optimal volumetric representation needs to be developed, although this difficulty has been overcome by the isogeometric boundary element method (IGABEM) and NURBS-enhanced finite element method (NEFEM), but these methods cannot inherit all of the advantages of isogeometric analysis. IGABEM is limited to linear problems and NEFEM loses a flexible refinement scheme and the ability to construct high order continuous field because of the use of polynomials in the domain.

• It is promising to combine isogeometric analysis with other methods. For example, the combination with the extended finite element method has achieved successful applications in fracture mechanics.