



## Evaluation of Selected Software Packages for Structural Engineering Works

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**Abstract:** There are confusions on the software to be used in the analysis and design of building structures as there are hundreds of Structural Engineering software applications in the world today. Majority of these software applications operate on certain criteria which makes them suitable for some projects and unsuitable for some. There is a need to research the strength and weakness of some of these software tools to help structural engineers in the selection of the best application in their daily tasks. In this paper, 17 different Structural Engineering software tools were evaluated based on their functional strengths. From the study, it was observed that different software applications have different functions and therefore, it is impossible to say one is better than the other. However, some software application can execute general structural engineering works which makes them versatile but at the same time, quite complex to handle when compared with others.

**Keywords:** Analysis, Computer Aided Design, Software, Structural Engineering

### 1. INTRODUCTION

Today, technology is spreading in almost every aspect of human life, from social life, construction, business management, medical or engineering. Science and Technology are closely related and go hand in hand, with each pollinating the other and bringing about an explosive collaboration.

A couple of years back, when personal computers and operating systems were in their emergent form, building planning and construction processes were very slow and strenuous. Advances in Civil Engineering and technological revolutions has empowered the construction firms to quicken the construction process and certifying strength and quality of the structures. Taking numerous years to construct a building structure is a thing of the past. Structural analysis and design software tools are now aiding construction to accelerate their analysis, design, and construction processes [1].

Software applications in Civil Engineering is usually classified into three types which are architectural, structural and management software applications. Architectural software applications are based on designing of interiors and exteriors, and planning. Structural software applications help in the analysis, design and in some cases, detailing of structural members, while project management software applications have the capacity to plan, organize, and guide (control) resource tools and come up with resource estimates.

Today, numerous design developments and enhancements arise which include structural design software which seeks to promote the capacity of a Structural Engineer to produce safe and sound designs especially when battling with complex building structures [2].

There are numerous software applications available to analyse and design massive projects in little time. There are 2-Dimensional and 3-Dimensional tools and most Structural Engineers employ the uses of the 3-D analysis and design tools in their day-to-day tasks because of its ease to operate and graphical user interface. These tools make modelling, analysing, and design of structures much more efficient. Most of these software applications have diverse and integrated functions, like modelling building structures of various materials, structural element analysis, geometrical error detections, and report output and graphical files [3]. In this paper, 17 different software applications for Structural Engineering works are evaluated and compared to show their strengths and weaknesses.

## 2. REVIEW OF STRUCTURAL ENGINEERING SOFTWARE PACKAGES

There are hundreds of software applications used for Structural Engineering works in the world today, and the prominent ones are reviewed in this section.

### 2.1 STAAD PRO (Structural Analysis and Design of Computer Programme)

This is a 3D structural analysis and design tool that is developed by Research Engineers and later acquired by Bentley Systems, which is a CAM/CAD software company. It is often considered as one of the leading structural analysis and design software, and widely adopted by millions of structural engineers all over the world. It features an array of essential tools that is needed for obtaining an analytical process on different structures. STAAD Pro models can be imported to OpenSTAAD (which is another Bentley product) to make the dependent models transferrable to third-party software applications. It also further integrates with some of other Bentley tools/products. Bentley boasted that their programs can confidently design concrete, timber, steel, aluminium, and cold-formed steel using over 90 international design codes and can generate structural design documents automatically [4]. It can analyse and design gravity and lateral loads.

STAAD.Pro can be used for both non-linear and linear static analysis, and it is also used at analysing time dependent effects.

Kulkarni et al. [5] studied the suitability of high-rise building design using STAAD PRO by modelling and subjecting a 30-storey building to seismic and wind load combination for analysis. The software has also been used for various structures like in the optimization of Fink truss by fully stressed design method [6], code-based design analysis of structures [7], and seismic analysis and design [8]. It is capable of analysing and designing civil engineering structures like buildings, bridges, plane, and space trusses, retaining walls, etc.

Despite the numerous advantages of using STAAD PRO in structural works, it has some limitations in its use [9]. These includes: (1) It is not for brick masonry work; (2) It does not show the amount of material used; (3) It is not for costing and estimating; (4) It requires proper skill for typical designs; (5) It gives uneconomical results for multi-storey structures; (6) It has limitations in modelling. Curvy boundary and parabolic beam cannot be modelled effectively and analyzed efficiently.

### 2.2 SAP2000 (System Application and Products)

SAP2000 is marketed and developed by Computer and Structures, Inc (CSI) ranging from 2D to 3D. SAP2000 is used over 160 countries around the world because of its effectiveness. It is generally used in the design of water tanks, bridges, buildings, retaining walls, among others. It has a user-friendly interface and provides modelling templates for geometrics of complicated structures. However, it possesses tools which makes it easy for basic modelling and analysis.

SAP2000 has been used in the earthquake analysis of structures by various researchers. It has the ability to carry out response spectrum analysis, pushover analysis, time history analysis, among others. Damam [10] carried out a comparative study on multi-storied building structure with and without shear wall using SAP2000 under different earthquakes. The suitability of response spectrum method of analysis using SAP2000 was confirmed. Poluraju and Rao [11] carried out a pushover seismic analysis of reinforced concrete frames using SAP2000 and they observed that the pushover analysis is a relatively simple way to explore the non-linear behaviour of buildings. Non-linear static pushover and time history analysis can also be carried out on buildings using SAP2000 [12]. The limitations of SAP2000 includes: (1) Its general-purpose nature makes it difficult to operate; (2) It is not suitable for detailing; (3) It cannot export its output to AutoCAD; (4) SAP2000 doesn't have a feature for designing continuum structural elements such as slabs, shells, and shear wall [13]. Thus, it cannot be used in the design of foundations and floor slabs.

### 2.3 ETABS (Extended Three-Dimensional Analysis of Building Structure)

ETABS is an integrated building design software developed by Computers and Structures Inc, also known as CSI. It is one of the most powerful software in structural engineering in the design of high-rise buildings [14]. Basic or advanced systems under static or dynamic conditions may be evaluated using ETABS. For a sophisticated assessment of seismic performance, modal and direct-integration time-history analyses may couple with P-Delta and large displacement effects.

ETABS was developed by the same company as SAP2000 but used for different purpose. It is mainly used to design and analyse high rise buildings systems where SAP2000 is used in the analyses and design of different structures like dams, bridges, water tanks, tunnels, retaining walls, etc. It is used worldwide due to its features in rapid modelling of framing systems and in analysing large and complicated building structures. ETABS has a user interface where it is integrated and do not depend on other programs. Columns, walls, slabs, beams, openings, and other elements can be designed and analyse using this one single interface. The structure can also be rendered in 3D within its environment.

Unlike SAP2000, ETABS can analyse structures nonlinearly, where users can design for and check stability of structures undergoing creep, shrinkage, and column shortening. Users can also produce a 2D nonlinear layer model to analyse concrete cracking and shear behaviour.

Another unique feature of ETABS is that users can use previously created ETABS templates to quickly start new models by just inputting their desired grid spacing, story numbers, slab sections, and loads.

A big advantage ETABS offers is the shear wall design, which is not available in SAP2000. Also, ETABS offers design of composite beam floors and auto-meshing of floors which are not available in SAP2000.

The limitations for ETABS includes: (1) SAP2000 offers post tension modelling whereas ETABS does not [3]. This is a major advantage of SAP2000 over ETABS; (2) It cannot be used to perform non-linear Pushover analysis; (3) It can model masonry but it is not the best tool for masonry because you can only remain in elastic region, and you do not have control on element type; (4) It cannot perform soil-structure interaction, which is the one of the reasons why it is not suitable for underground water tanks; (5) It cannot be used in the design of foundations and floor slabs.

#### **2.4 TEKLA Structural Designer**

Tekla is a software that consists of programs for analysis and design, detailing and project communication model-based software products for building, construction, and infrastructure management. Tekla structures is ideal for steel detailers and fabricators, bridge engineers, concrete contractors, structural engineers, precast detailers and producers, rebar works, etc [15]. Its limitations include: (1) It is not suitable for detailing; (2) It cannot export its output to AutoCAD; (3) It requires proper skills for typical designs; (4) It cannot be used in the design of foundations and floor slabs.

#### **2.5 SAFE**

SAFE is a software that is meant for the engineering analysis, design and detailing of elevated floor and foundation slab systems. It also belongs to the CSI family. SAFE is an easy-to-use software for structural engineers as it provides all the necessary tools that is needed for the modelling, analysis, design and detailing of a concrete slab and foundation systems. Modelling, analysis, and design procedures feature a suite of sophisticated tools and applications, couple with post-tensioning, punching-shear, and beam detailing, and integrate the influence of soils, ramps, columns, braces, walls (rectilinear or curvilinear), and other interfacial elements. Interoperability with SAP2000 and ETABS allows users to import models, loading, and displacement fields into SAFE for more advanced local assessment of slab systems within larger structures [2].

Its major limitations include (1) It cannot be used for a complete building design; (2) It is only suitable for foundations and underground structures; (3) It is dependent on other software (like ETABS) for complete analysis and design of a full building structure.

#### **2.6 RISA 3D**

This is another popular 3D analysis and design tool for creating general structures such as buildings, bridges, arenas, industrial structures, crane rails, and more. It is fast, productive, and accurate. It has an intuitive interface that integrates with many other products like RISAFloor and RISA Foundation. It comes packed with the latest steel, cold-formed steel, concrete, aluminium, masonry, and timber design codes [16]. This, in turn, provides the tools needed to manage the multi-material projects with ease. The seamlessly integration with RISAFloor and RISAFoundation makes it easy to be interlinked for detailing, drafting, and BIM packages for a complete building design solution [17]. The limitations of RISA 3D include: (1) It relies heavily on its other family products (like RISAFloor, RISA Foundation, RISAConnection) to successfully analyse and design structures; (2) It cannot be used to perform non-linear Pushover analysis.

#### **2.7 GT STRUDL**

GT STRUDL is one of the most widely used fully integrated structural analysis software solutions in the world. It has a proven track record in a variety of civil engineering applications. It has the ability to perform linear and nonlinear static analysis, steel design, reinforced concrete design, base plate analysis, offshore jacket and pile analysis, and others [18].

Its major limitations include (1) It relies on a third-party software like AutoCAD for its graphical user interface; (2) It cannot export its output to .dxf format for proper detailing.

#### **2.8 PROKON**

Prokon can be used for frame and finite element analysis, steel member design, steel connection design, reinforced and prestressed concrete design, CAD and reinforced concrete detailing, timber member design, masonry design, pronet water network analysis, general structural analysis, and a collection of geotechnical analysis [19].

Prokon has some major limitations which include (1) It can only handle individual members and not a whole structure; (2) It is not suitable for seismic analysis.

#### **2.9 Robot**

Autodesk Robot Structural Analysis Professional software provides structural engineers with advanced building simulation and analysis capabilities for large, complex structures. Robot offers a smooth workflow which enables structural engineers to carry out simulation and analysis of structures in little time. It has BIM-integrated workflows by having the ability to exchange data with Revit and other design tools.

Design codes all over the world are available on Robot unlike other software applications. Robot can be used for wind load simulation, static, modal and non-linear analysis of structures, finite element auto-meshing, structural design, among others [20]. Its limitations include (1) Not as user friendly when compared with ETABS or STAAD pro; (2). It takes more time to import IFC models when compared with other software applications [21].

## 2.10 CSC Orion

Orion provides a dedicated analysis, design and drafting solution for reinforced concrete building structures. It offers a unique central 2D/3D modelling environment from which automatic analysis, design and drafting is derived for the engineer. Detailed design and drafting time are dramatically reduced in Orion [22].

Detailed calculations, material quantities, structural layout plans, beam and slab elevations and column schedules are all produced automatically from one central model [23]. Orion has some limitations which include (1) it can only handle reinforced concrete structures, does not do steel members; (2) It cannot be used for wind and seismic analysis of building structures; (3) It can only be used for buildings and no other structures; (4) It does not support IFC for easy interoperability.

## 2.11 Prota Structure

Prota Structure is a powerful application that helps engineers in modelling, analysing, and designing steel and concrete buildings quickly and accurately. Prota Structure is owned by a Turkish company called Prota Engineering and it operates within strictly technical institutional structure that consists of different experts as partners. It is known to be fast in delivering projects with full consolidated concrete and steel design using a single central model. It is also a state-of-the art structural model using 3D finite element analysis with numerous analysis preferences and shell element support for storey and shear walls [24]. These analysis options include vertical and lateral elastic analysis, equivalent static earthquake load, response spectrum analysis, time-history, pushover, staged construction, P-delta, temperature difference and seismic isolators.

Apart from using various globally recognized codes, including specialist seismic requirements for analysing and designing buildings, it also offers fully automated RC detailing in drawing sheets with its dynamic quantity tables along with fast engineering macros including retaining wall, stair, pile analysis and design and detailing. It also has custom link for RC and Steel models with full-fledged BIM platforms such as Autodesk and Tekla structure [25]. Some of the major limitations of Prota structures include: (1) It cannot be used for the analysis and design of bridges; (2) It cannot perform seismic analysis; (3) It can only be used for steel and reinforced concrete buildings.

## 2.12 ANSYS (Analysis SYSTEM)

Ansys is a Multiphysics engineering simulation software which can be used across all the fields of engineering. Ansys Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analysing strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes.

Ansys structural analysis software is used across industries to help engineers optimize their product designs and reduce the costs of physical testing. Its applications include strength analysis, vibration, thermal analysis, durability, rigid body dynamics, hydrodynamics, composites, impacts, optimization, High Performance Computing (HPC) for Finite Element Analysis (FEA), Topology optimization, additive manufacturing, etc [26]. Its limitations in structural engineering works include: (1) It can only be used for analysis and not design; (2) It relies on external software like Solidworks for modelling complex shapes; (3) It requires a specialist to handle as it was made for advance structural engineering.

## 2.13 Abaqus

Abaqus is a Multiphysics simulation software suite for Finite Element Analysis (FEA) developed by Dassault Systèmes. The Abaqus Unified FEA product suite is part of the SIMULIA brand and offers powerful and complete solutions for both routine and sophisticated engineering problems covering a vast spectrum of industrial applications [27]. The Abaqus product suite consists of four core software products which include Abaqus/CAE (Complete Abaqus Environment), Abaqus/Standard (utilises implicit integration schemes for static and low-speed dynamic events), Abaqus/Explicit (utilises an explicit integration scheme to solve highly nonlinear problems, well suited to simulate brief transient dynamic events such as crash analysis, ballistic impact and drop-testing), and Abaqus/CFD (Computational Fluid Dynamics capabilities).

Its major strength to ANSYS is that ANSYS relies on the partnership with DYNA for explicit analysis whereas ABAQUS has it all integrated. You can switch from explicit/implicit between analysis steps. In terms of industries, ABAQUS has greater penetration in the Automotive while ANSYS is preferred in the Energy Industry. ABAQUS is very good for modelling material and structural problems. It has many constitutive models to analyse the non-linear behaviour of steel, concrete, soil, etc. Its limitations in structural engineering works include: (1) It can only be used for analysis and not design; (2) It relies on external software like Solidworks for modelling complex shapes; (3) It is complex to handle as it combines multiple-physics solvers together.

## 2.14 Quick Civil Series

Civilsoft Quick Civil Series (also called QuickStructure) is computer aided design software Written by Engr Henry Orji. The software is used for structural engineering, modelling, loading, detailing, bar schedule and bill of material schedule. Civilsoft Technologies is a company that specializes in providing civil engineering professionals and students with high tech cutting edge civil engineering computing technology which will enable them to compete in a world that is fast becoming highly technological advanced.

QuickStructure can be used for 2D/3D structural modelling, analysis and design, detailing, bar schedule, reinforced concrete and steel design, steel roof truss modelling, loading, analysis and design, foundation design, etc [28]. Its limitations

include: (1) It cannot perform seismic analysis; (2) It does not support IFC file import and export; (3) It can only be used in the design and analysis of reinforced concrete buildings; (4) It cannot be used to model irregular and complex structural members like curved beams, columns of various shapes, etc.

### 2.15 CSI Bridge

CSiBridge is a state-of-the-art software for the modelling, analysing, designing, and rating of simple and complex bridges. It is powered by the same team behind SAP2000, the comprehensive software solution dedicated to all-purpose structural analysis and design.

It provides a unified graphical interface for modelling, design, analysis, load rating, scheduling, and reporting tasks. It includes several templates to help get started with bridge structures. CSiBridge design allows for quick and easy design and retrofitting of steel and concrete bridges.

Its limitations include: (1) It can only be used for bridges; (2) It does not support .dxf export for proper detailing in AutoCAD; (3) It cannot be used for foundation design.

### 2.16 TEDDS

TEDDS is a program that allows you to automate your daily calculations. It was produced by CSC (the company that also produced Orion) before being acquired by Trimble (creator of Tekla). You can access a large library of automated structural and civil calculations, choose from a range of international codes, make the transition to Eurocodes effortlessly and compare different design options and make changes quick. It is powerful software used to automate repetitive structural calculations, and also combine it with 2D frame analysis.

Tedds has some major limitations which include (1) It can only handle individual members and not a whole structure; (2) It is not suitable for wind and seismic analysis; (3) It limited to 2D.

### 2.17 REVIT STRUCTURES

Revit Structures is a Building Information Modelling (BIM) software developed by Charles River Software in 1997 but acquired by Autodesk in 2002 [29]. It provides a robust tool to drive efficient design process in a BIM environment, making it possible to work with other construction disciplines using Autodesk CAD software like Revit Architecture and Revit MEP.

Revit Structures aids workflow between architectural conceptual design through to structural designs and drafting. Thus, the effect and impact of changes in models can be assessed immediately, leading to a reduction in errors, as existing drawings are updated automatically by Revit's parametric technology, aiding coordination between Architects, Engineers and Contractors.

Revit Structures is capable of modelling 3D concrete reinforcement in an advanced BIM environment, connect steel design and detailing workflows, create accurate and detailed documentation of concrete and steel designs, carryout structural analysis and export same to analysis and design applications [30].

## 3. COMPARISON OF THE SOFTWARE PACKAGES

The software packages were compared based on their functional strengths like the structure types they handle (building, bridge), maximum number of storeys, single-structure software or multipurpose, full structure or individual members, 3D or 2D, rendering ability, analysis, design, detailing, quantities, wind analysis, seismic analysis, etc.

### 3.1 Interoperability

Today, interoperability is one important characteristic a good structural engineering software must possess. It is the core of Building Information Modelling (BIM) data exchange in the AEC domain. A good software must have the ability to import and export data from different sources which is the goal of BIM. Table 1 shows the interoperability of the structural engineering software applications. It should be noted that the tick sign ( ✓ ) indicates the ability of the software to perform/possess such functionality while the reverse is for the blank spots on the table.

Table 1: Data Exchange for Structural Engineering Software Applications

S/No	Application	Import					Export				Direct Link
		CIS/2	IFC	DXF & DGN	SDNF	SAT	CIS/2	IFC	DXF & DGN	SDNF	
1	STAAD-Pro	✓					✓				Tekla structures, Bentley
2	SAP2000	✓	✓				✓	✓			Revit Structures
3	ETABS	✓	✓				✓	✓			Revit Structures
4	TEKLA		✓	✓				✓	✓		

5	SAFE	√	√						√	√	√								
6	RISA 3D				√							√		√					Revit Structures
7	GT-STRU DL	√				√			√										
8	PROKON	√			√	√			√				√		√				
9	Robot	√	√																Revit Structures
10	CSC Orion				√									√					
11	Prota Structures		√	√								√	√						
12	ANSYS																		
13	ABAQUS																		
14	QuickCivilSeries					√								√					
15	CSI Bridge	√	√						√	√									
16	TEDDS																		
17	Revit Structures	√	√	√										√					Revit Architecture

### 3.2 Functionality of the software packages

To show the suitability of the software applications for different tasks, their functions are presented in Table 2 according to their ability.

Table 2: Software and their Functions

Functions	SOFTWARE APPLICATIONS																
	STAAD-Pro	SAP2000	ETABS	TEKLA	SAFE	RISA 3D	GT-STRU DL	PROKON	Robot	CSC Orion	Prota Structures	ANSYS	ABAQUS	QuickCivilSeries	CSI BRIDGE	TEDDS	Revit Structures
Buildings	√	√	√	√		√	√	√	√	√	√			√		√	√
Bridges	√	√		√		√	√		√						√		√
Towers	√	√		√		√	√		√			√	√				√
Retaining walls	√	√		√	√	√	√	√	√		√	√	√			√	√
Full Structure	√	√	√	√		√	√		√	√	√	√	√	√	√		√
Members	√	√			√	√		√				√	√			√	√
3D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√
Analysis	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Design	√	√	√	√	√	√	√	√	√	√	√			√	√	√	√
Detailing	√	√	√	√	√	√	√	√	√	√	√			√	√	√	√
DXF, Detail, Export					√				√	√	√			√			√
Wind Analysis	√	√	√	√	√	√	√		√		√	√	√		√		√
Seismic Analysis	√	√	√	√	√	√	√		√		√	√	√		√		√
Foundation Design	√	√		√	√	√	√	√	√	√	√			√	√	√	√
Staircase Design	√	√		√	√	√	√			√	√			√		√	√

**3.3 Multifunctionality of the software packages**

In terms of multifunctionality, Figure 1 shows the ranking of each software according to the number of functions they can perform. Revit Structures has 15 unique functions, STAAD-Pro, SAP2000, and RISA has 14 unique functions, Tekla, GT-STRUDL and Robot have 13 unique functions, Prota has 12, SAFE 10, CSC Orion, QuickCivilseries and CSI Bridge has 9 while ETABS, Prokon, ANSYS, ABAQUS and TEDDS have 8 unique functions.

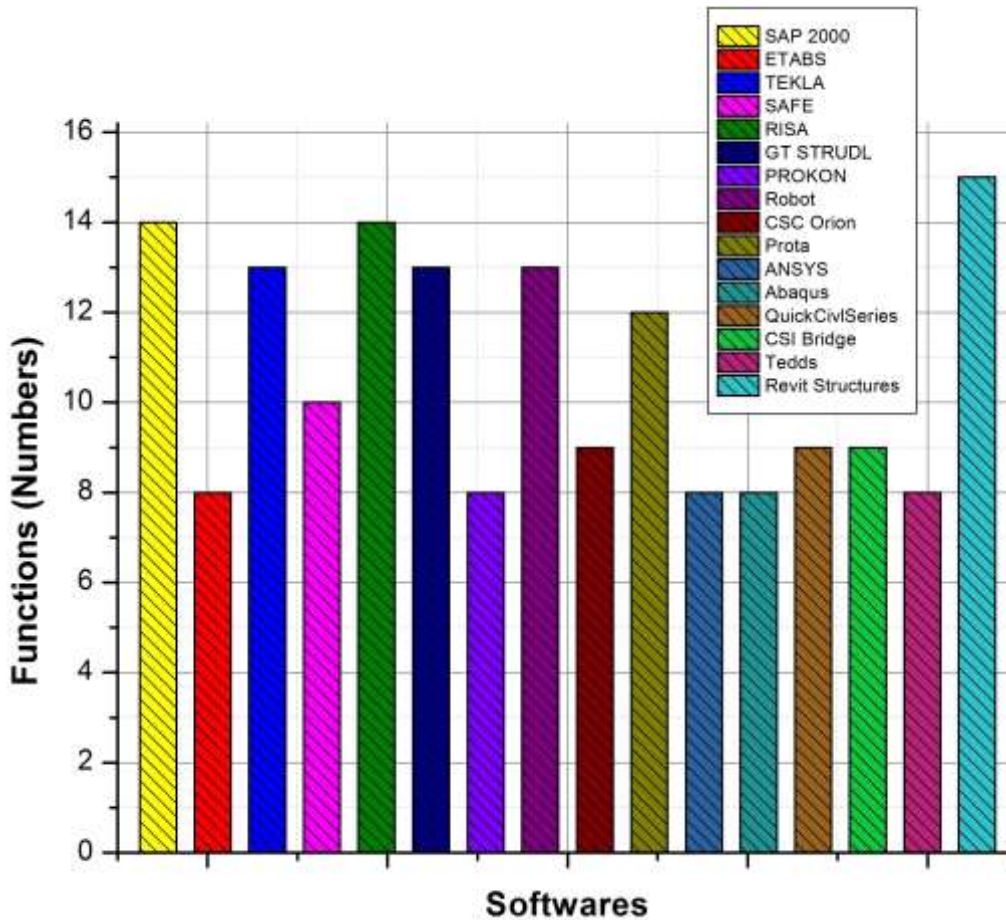


Figure 1: Multifunctionality of Software Applications

**4. COST OF SUBSCRIPTION FOR SOFTWARE PACKAGES, AVAILABILITY OF USER SUPPORT AND SIZE OF USERBASE**

The cost of yearly subscription for each of the software packages considered in this study, the availability of user support and the size of their userbase is presented in Table 3. The yearly subscription of the software packages ranges from \$450 - \$30,000. All the software packages reviewed have user support by the manufacturers. However, the size of userbase is considered as a classified information by the developers of the software packages and such information is not available for public consumption.

Table 3: Yearly subscription, user support and size of userbase for softwares

S/No	Application	Yearly Subscription (\$)	Availability of user support	Size of userbase
1	STAAD-Pro	2,633	√	Not available
2	SAP2000 (Basic)	2,000	√	Not available
	SAP2000 (Plus)	5,000	√	Not available
	SAP2000 (Advanced)	8,000	√	Not available
	SAP2000 (Ultimate)	12,000	√	Not available
3	ETABS (Plus)	5,000	√	Not available
	ETABS (Nonlinear)	8,000	√	Not available

	ETABS (Ultimate)	12,000	√	Not available
4	TEKLA	7,500	√	Not available
5	SAFE (Standard)	4,000	√	Not available
	SAFE (Post-tensioning)	6,000	√	Not available
6	RISA 3D	8,000	√	Not available
7	GT-STRUDL	1,495	√	Not available
8	PROKON	4410	√	Not available
9	Robot	2965	√	Not available
10	CSC Orion	450	√	Not available
11	Prota Structures	Not available	√	Not available
12	ANSYS	30,000	√	Not available
13	ABAQUS	20,000	√	Not available
14	QuickCivilSeries (Basic)	120	√	Not available
	QuickCivilSeries (Standard)	400	√	Not available
	QuickCivilSeries (Enterprise)	630	√	Not available
	QuickCivilSeries (Professional)	1,100	√	Not available
	QuickCivilSeries (Ultimate)	1,500	√	Not available
15	CSI Bridge (Plus)	9,000	√	Not available
	CSI Bridge (Advanced)	16,000	√	Not available
	CSI Bridge (Advanced with rating)	20,000	√	Not available
16	TEDDS	2,000	√	Not available
17	Revit Structures	2,425	√	More than 2 Million

## 5. CONCLUSIONS

From the study, different applications have different functions and therefore, it is impossible to say one is better than the other. Some are for general structural works (Revit Structures, SAP2000, STAAD-Pro, RISA 3D, GT-STRUDL), while some are just for a particular structure type (CSI Bridge, ETABS). Some software application can execute general structural engineering works which makes them versatile but at the same time, quite complex to handle.

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